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CLASS-BOOK
OF
ELEMENTARY GEOLOGY

BY
FREDERICK WOLLASTON HUTTON,
F.G.S. &c.

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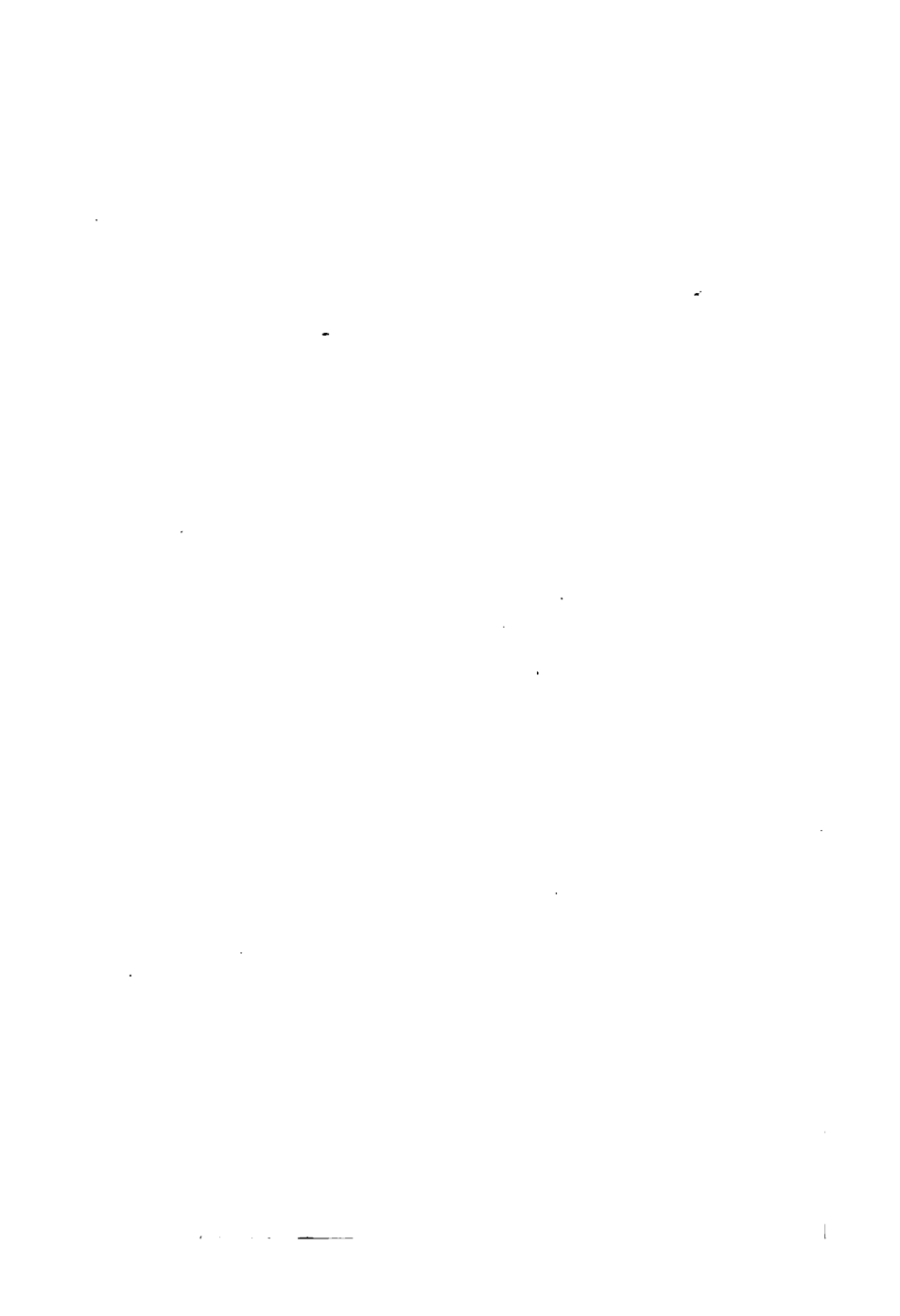
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ELEMENTARY GEOLOGY.



BY
FREDERICK WOLLASTON HUTTON,
F.G.S., &c.
PROVINCIAL GEOLOGIST, OTAGO, NEW ZEALAND, AND LECTURER ON
GEOLOGY AND ZOOLOGY TO THE OTAGO UNIVERSITY.

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"It is not too much to say that in our time practical geology has been one of the best schools of philosophical and general culture of mind."

WHEWELL,
History of the Inductive Sciences, iii. p. 571.

PREFACE.

THIS little book is intended to meet the want in the Colonies of a class-book of Geology, which, while it enters with sufficient fulness into those generalities of the science that apply to all countries, omits details of the geological structure of Britain or America, such as fill the greater part of other text-books written in the English language, and which add greatly to their price without being of any use to junior students. Indeed, these details are sometimes worse than useless. I myself know more than one amateur student of Geology who has been sorely puzzled at not having come across the Old Red Sandstone or the Mountain Limestone in New Zealand, but is still somewhat comforted by the conviction that at any rate he knows where to lay his hand on the Millstone Grit.

It has been my wish to adapt it to the wants of teachers, and to make it as elementary and as concise as possible without omitting altogether any point that it is important for the student to know; but I am afraid that I have not been equally fortunate in all the chapters.

I lay no claim to originality for any of the views expressed in it—indeed, originality would be quite out of

place in an elementary class-book ; but I have endeavoured to collect together the best founded opinions on those subjects which still form matter for discussion.

In the division of Volcanic Action into two distinct classes, I have followed Durocher and Baron Richthofen, as their views agree very closely with my own experience among volcanic districts in New Zealand ; but I have not thought it advisable at present to make relative age an element in the classification of eruptive, any more than in sedimentary, rocks.

I have purposely refrained from any description, or even mention, of the characteristic Fossils of the various periods, for this belongs to Palæontology and not to Geology ; and without a systematic study of Zoology and Botany, the knowledge of a few names of extinct animals and plants could lead to no possible good.

I have to thank my colleague, Professor Shand, for looking over and revising the propositions relating to Geological Surveying.

DUNEDIN, *April 1874.*

CONTENTS. .



	PAGE
INTRODUCTION,	9
Definition of Geology.	

CHAPTER I.

GENERAL CONSIDERATIONS,	13
Cosmical Relations of the Earth—Composition of the Earth—Internal Temperature of the Earth—Division of the Rocks forming the Surface of the Earth.	

CHAPTER II.

ROCK-FORMING MINERALS,	17
----------------------------------	----

CHAPTER III.

DENUATION,	22
----------------------	----

CHAPTER IV.

FORMATION OF SEDIMENTARY ROCKS,	25
Formation of Sandstone and Slate—Intercalation of Beds—Change in the Lithological Character of Beds—Sedimentary Rocks originally horizontal—Formation of Limestone—Formation of Coal.	

CHAPTER V.

	PAGE
METAMORPHISM,	33
Pseudomorphism — Consolidation — Metamorphism — Alteration — Decomposition.	

CHAPTER VI.

DESCRIPTION OF SEDIMENTARY ROCKS,	36
Inorganically-derived Rocks—Organically-derived Rocks.	

CHAPTER VII.

POSITION OF STRATA,	42
-------------------------------	----

CHAPTER VIII.

VOLCANIC ACTION,	46
Paroxysmal Eruptions—Massive Eruptions.	

CHAPTER IX.

DESCRIPTION OF ERUPTIVE ROCKS,	50
Siliceous Rocks—Felspathic Rocks—Pyroxenic Rocks—Older and Newer Eruptive Rocks—Determination of Eruptive Rocks.	

CHAPTER X.

MODE OF OCCURRENCE OF THE OLDER ERUPTIVE ROCKS,	60
Contemporaneous Eruptive Rocks—Intrusive Eruptive Rocks.	

CHAPTER XI.

STRUCTURE OF ROCK MASSES,	63
Joints—Faults—Cleavage—Slickensides.	

CONTENTS.

vii

CHAPTER XII.

MOVEMENTS OF THE SURFACE OF THE EARTH, . . .	PAGE 67
Sudden Movements—Slow Movements—Coral Islands— Internal Evidence—Course of the Movements.	

CHAPTER XIII.

PROOFS OF FORMER DENUDATION,	71
--	----

CHAPTER XIV.

EARTHQUAKES,	73
Earthquakes on Land—Earthquake Waves—Secondary Effects of Earthquakes—Distribution of Earthquakes.	

CHAPTER XV.

PALÆONTOLOGY,	80
Fossils—Imperfection of the Geological Record.	

CHAPTER XVI.

CHRONOLOGICAL CLASSIFICATION OF ROCKS,	84
Sedimentary Rocks—Nomenclature—Eruptive Rocks.	

CHAPTER XVII.

PHYSIOGRAPHY,	91
Mountains—Valleys—Lakes—Plains—River Deposits.	

CHAPTER XVIII.

MINERAL VEINS,	97
Concretions—Non-metalliferous Veins—Metalliferous Veins—Kinds of Veins—Contents of Veins—Direc- tion of Veins—Origin of Veins—Filling of Veins— Age of Metals.	

CHAPTER XIX.

THE ART OF MINING,	PAGE 104
Vein-mining—Bed-mining—Ventilation of Mines—Alluvial Mining—Describing Mines.	

CHAPTER XX.

GEOLOGICAL SURVEYING,	112
Procedure in the Field—Construction of Sections—Method of Examining a New Country.	
APPENDIX,	117
A. Problems in Geological Surveying.	
B. Table of Signs and Colours.	
INDEX,	125

INTRODUCTION.

GEOLOGY is that branch of science which investigates the structure of the earth, and the causes which have led to that structure. These investigations cannot be said to have been begun before the year 1500 A.D., for the previous guesses of Pythagoras, Aristotle, and Strabo were not supported by any examples or proofs. But in the early part of the sixteenth century the occurrence of fossil shells in rock attracted considerable attention in Italy, and their true nature was explained by the celebrated painter *Leonardo da Vinci*, and by *Fracastoro* (1517). These views, however, excited great opposition: fossils were said to be owing to fermentation in the rocks, to the influence of the stars, or other equally fantastical causes; and it was not until 1669, when *Steno*, a Dane living in Italy, showed that many of the fossil shells belonged to still living species, that this first fundamental point was settled. The question then arose as to whether all or any of the fossils had been buried by the Noachian deluge, and this took another 150 years to decide.

Meanwhile, however, other branches of Geology had made considerable progress. *Leibnitz*, the celebrated

mathematician, suggested in 1680 that the earth had once been an incandescent liquid mass, and was gradually cooling. In 1740 *Antonio Moro* pointed out that the faults and dislocations of rocks proved that the land had been upheaved. He described subaerial denudation, and showed that it was compensated for by elevation; and he also distinguished the volcanic from the sedimentary rocks that contained fossils.

Tylas, a Swede (1750), and *Lehmann*, a German (1756), discovered that the order of superposition of rocks was never inverted. *Werner* (1775), Professor of Mineralogy in the School of Mines at Freiberg, in Saxony, first pointed out the practical importance of Geology to miners and engineers; but he believed that all rocks, including even basalt, had been precipitated from water in successive universal formations from a common menstruum, or "chaotic fluid," and that there were no volcanoes in the early ages of the world.

Dr James Hutton (1788) of Edinburgh was the first to teach that all the changes on the surface of the earth had been brought about by the slow agency of existing causes, and he refused to admit any unknown agent into his theory. He explained how the stratified rocks were but the results of denudation, how they were afterwards hardened and metamorphosed by heat, and how the eruptive rocks had been injected into fissures in a molten state, and owed their compactness to pressure. Granite, he taught, was formed by the igneous fusion of sedimentary rocks. He showed that it was younger than the rocks that it traversed, and boldly stated that in the economy of the world he could find "no traces of

a beginning, no prospect of an end." This caused a revolution in the science, and first gave to geologists an idea of the enormous length of past time. Hutton did not, however, admit any subsidence of the earth's surface, and failed to see that the cooling of the globe must in time end the present order of things.

William Smith (1790), an English land-surveyor, at about the same time discovered not only, as Tylas had done, that the order of strata was never inverted, but that each formation might be identified at distant places by its fossils. During the following twenty-five years he travelled on foot over the whole of England, succeeded in dividing the rocks into natural groups, and constructed the first geological map that showed truly the successive formations of the country. This was the turning point in Geology. A sound law of succession having been discovered, geologists now abandoned speculation, and set resolutely to work to find out the relative ages of rocks from all parts of the globe.

The next great step in advance was made by *Dr Buckland*, who in 1820 announced that the mica-schists of the Alps were of Jurassic age, and thus dispelled the idea that the crystalline schists must necessarily be older than fossiliferous rocks. This was followed by the publication, in 1830, of *Sir C. Lyell's* "Principles of Geology," which successfully refuted the doctrine then prevalent among geologists, that each great period of the earth's history had been closed by a universal catastrophe, which had shattered the crust of the globe, annihilated all living beings, and caused the sudden elevation of mountain chains.

The last important step in theoretical Geology was in 1862, when *Sir W. Thomson* of Glasgow, in a paper on the "secular cooling of the earth," showed that a limit must be placed on the enormous demands of time made by the followers of Hutton, and also gave precision to the doctrine of geological evolution—that is, the slow progress in the order of nature—as against the doctrine of absolute uniformity, propounded by Sir C. Lyell.

ELEMENTS OF GEOLOGY.

CHAPTER I.

GENERAL CONSIDERATIONS.

Cosmical Relations of the Earth.—The earth revolves round the sun in an elliptical orbit, which approaches very nearly to a circle, the sun being situated in one focus, which is $\frac{1}{80}$ of the mean distance between the sun and the earth from the true centre ; so that when the sun is in *perigee*, or nearest to the earth, it is $\frac{1}{80}$ of the mean distance, or about three millions of miles nearer to the earth than when it is in *apogee*, or furthest from the earth.

Owing to the attraction of the planets, especially Jupiter and Saturn, the eccentricity of the ellipse changes in an irregular manner between the limits of $\frac{1}{13}$ and $\frac{1}{880}$ of the mean distance, which always remains the same ; so that when the eccentricity is at its maximum, the sun is fourteen and a half millions of miles nearer to the earth when in *perigee* than in *apogee*, while, when the eccentricity is at its minimum, the difference in distance is only about half a million of miles. At present the eccentricity is diminishing.

From the same cause the major axis of the earth's orbit slowly changes its direction, in the same plane, at the rate of 11'8" per annum, so that it revolves round the sun once in 109,830 years. This is called the *re-*

volution of the apsides, because the line joining the points of perigee and apogee, or the major axis of the earth's orbit, is called the line of apsides.

In shape the earth is an oblate ellipsoid of revolution, the polar diameter being 7899 miles, and the equatorial diameter about 7926 miles ; so that we may look upon it as a sphere 7899 miles in diameter, girdled round with a mass of matter thirteen miles thick at the equator, and tapering off towards each pole. This maintains the permanence of the axis of rotation with reference to its position in the earth itself, for the axis of rotation must coincide with an axis of symmetry, and the effect caused by the elevation of a mountain chain must be always very small in comparison with the centrifugal force exerted by the equatorial belt. It follows from this, that if any outside disturbing force caused the position of the equatorial belt to shift, the axis of rotation must shift with it.

Such a disturbing cause is the attraction of the sun and moon on the protuberant matter round the equator, which, combined with the rotation of the earth, causes the polar axis to describe a circle in the heavens round the pole of the ecliptic as a centre, and at a distance of $23^{\circ} 28'$ from it, in 25,868 years. Consequently, during one revolution of the polar axis the sun will be in perigee at the winter solstice, the vernal equinox, the summer solstice, and the autumnal equinox in succession. This is called the *precession of the equinoxes*.

But the line of apsides, as already explained, also shifts, but in an opposite direction, thus making the real rate of change the same as if the *perihelion*, or the position of the earth when nearest the sun, made a complete revolution in 20,984 years, so that winter and summer change places about every 10,500 years. At present,

perihelion occurs eleven days after the solstice—that is, on the 1st January.

Owing to the varying position of the plane of the moon's orbit, a subordinate movement is given to the axis of the earth, which makes the pole describe every nineteen years a small ellipse, the major axis of which is directed towards the pole of the ecliptic. This is called *nutation*, and, combined with precession, causes the pole of the earth to move in an undulating ring round the pole of the ecliptic.

Owing also to the joint attraction of the planets, the position of the plane of the ecliptic also varies about 48" in a century, which has the effect at present of bringing the ecliptic every year nearer to the equator. This variation, however, must have very moderate limits, its maximum being not more than 4° on each side of a mean position. This *change of obliquity of the ecliptic*, combined with the precession of the equinoxes, causes the real curve described in the heavens by the polar axis round the pole of the ecliptic to be an undulating spiral, which gradually but irregularly decreases and increases again, the whole breadth of the ring travelled over being about 8°.

Composition of the Earth. — The whole substance of the earth—including air, water, plants, and animals—is made up of sixty-four different elements, either simple or combined in different ways ; but of these thirteen only are abundant, six being metals, and the other seven non-metallic bodies. They are—

NON-METALLIC BODIES.

Oxygen.	Carbon.
Hydrogen.	Sulphur.
Nitrogen.	Silicon.
Chlorine.	

METALS.

Calcium.	Magnesium.
Sodium.	Aluminium.
Potassium.	Iron.

Internal Temperature of the Earth. — The mean specific gravity of the globe is about 5·5, which is more than twice that of the rocks on the surface. If, however, the earth is composed of materials as heavy as, or heavier than, those found on the surface—which must certainly be the case,—the immense pressure caused by gravitation to the centre would make the mean density of the earth far greater than the observed density, unless the force of gravity was counteracted by some other force situated in the interior of the earth, and we know of no other power but the expansive force of heat capable of producing such a counteracting action.

This deduction is further strengthened by the fact that the temperature of the earth does actually increase the deeper we descend into it, at a rate which varies in different districts, but, on an average, is 1° F. for about every fifty feet. From this it follows that heat is constantly passing outward from the interior of the earth, and being radiated away into space ; consequently the earth must be gradually cooling.

Thermal springs also show that the interior of the earth is highly heated, for the very different compositions of the various springs, as well as the facts that hot springs are sometimes as pure as cold ones, and that hot and cold springs are often found close together, and containing nearly the same materials, all prove that the heat is not due to chemical causes.

The temperature of the surface of the earth depends upon its power of absorbing during the day the heat radiated by the sun. One portion of this heat is radiated back by the earth during the night, while the rest passes slowly into the earth to a depth of from 40 to 100 feet, below which its effect is inappreciable. This depth is

called *the stratum of invariable temperature* : above it the temperature varies with the seasons ; below it the temperature increases with the depth. The stratum of invariable temperature is always about 1° F. above the mean annual temperature of the surface. If, therefore, the temperature of the earth increases 1° F. for every 50 feet, all water below a depth of from 6000 to 10,000 feet, according to the mean temperature of the surface, must be boiling hot ; at a depth of 20 miles, all rocks must be red hot ; and below 35 miles, the temperature must be far above the melting-point of rocks on the surface.

The **Rocks** forming the surface of the earth may be divided into two great classes, called *sedimentary* and *eruptive* respectively. The former occur in regular layers or *strata*, and are therefore often called the *stratified rocks*, while the latter are usually found in irregular masses, and are consequently sometimes called the *unstratified rocks*.

CHAPTER II.

ROCK-FORMING MINERALS.

A Mineral is an inorganic substance of homogeneous structure. Minerals are distinguished from each other by their chemical composition, their fusibility before the blowpipe, their specific gravity, their hardness, lustre, and crystalline form.

Crystals are the regular forms that minerals assume. Many crystals split more easily in certain directions than in others. These directions are called the *cleavage planes* of the crystal, which are always smooth and shining.

Rocks are composed of very few minerals, although many others are occasionally found in them. These latter are called *accessory minerals*, and are not essential constituents of the rock.

ROCK-FORMING MINERALS.

QUARTZ.	TALC GROUP—
FELSPAR GROUP—	Chlorite.
Orthoclase.	Serpentine.
Albite.	Talc.
Oligoclase.	GARNET GROUP—
Labradorite.	Olivine.
MICA GROUP—	Garnet.
Muscovite.	CALCITE.
Biotite.	DOLOMITE.
PYROXENE GROUP—	GYPSUM.
Hornblende.	ROCK SALT.
Augite.	

Quartz or Silica.—Crystals hexagonal; no cleavage; glassy lustre; cannot be scratched with a knife; infusible. This mineral constitutes nearly one half of the solid crust of the earth.

Chert and *Flint* are impure compact silica; chert is more brittle than flint.

Jasper contains some clay, and is coloured by oxide of iron or manganese.

SILICATES.

(*Do not effervesce with acids.*)

Felspar Group.—The felspars are nearly as hard as quartz, but can be scratched with a knife; they cleave in two directions; the lustre is generally rather pearly;

and they are fusible at the edges. Felspar can be distinguished from quartz by its lustrous cleavage planes.

MONOCLINIC FELSPARS.

The two most perfect cleavage planes forming an angle of 90° . Basal cleavage plane smooth.

Orthoclase, or Potash Felspar.—Trisilicate of alumina with silicate of potash. Generally reddish or yellowish, sometimes colourless, rarely green; fusible with difficulty; not affected by acids.

Sanidine, or Glassy Felspar, is a grey or yellowish translucent variety, with a glassy lustre.

Monoclinic felspar is never found in the pyroxenic rocks.

TRICLINIC FELSPARS.

The two most perfect cleavage planes forming an angle less than 90° . Basal cleavage plane often finely striated.

Albite.—Trisilicate of alumina with silicate of soda. Generally colourless, or nearly so; fusible with difficulty; scarcely affected by acids; occurs only in the silicious rocks.

Oligoclase.—Bisilicate of alumina with silicate of soda. Greyish or greenish; easily fusible; slightly affected by acids; usually much weathered; occurs in all orders of eruptive rocks.

Labradorite.—Monosilicate of alumina with silicate of lime. Nearly always dark coloured; easily fusible; powder soluble in heated hydrochloric acid; occurs only in the pyroxenic rocks.

Mica Group.—Usually found in thin laminæ, owing

to their very perfect basal cleavage across the prisms ; laminæ elastic.

Muscovite.—Yellow or potash mica. Silicate of alumina with silicate of potash. Generally light coloured ; not affected by sulphuric acid ; not found in the pyro-nenic rocks ; most common in the silicious rocks.

Biotite.—Black or magnesia mica. Silicate of alumina with silicate of magnesia. Generally dark coloured ; decomposed by concentrated sulphuric acid ; found in the pyroxenic, felspathic, and silicious rocks.

Pyroxene Group.—Always dark coloured, and generally found in prisms. Anhydrous silicates of magnesia, lime, and iron.

Hornblende.—Cleavage perfect ; parallel with the sides of the prism ; the larger angle $124^{\circ} 30'$; often in long slender prisms ; usually associated with orthoclase or oligoclase, never with labradorite.

Augite.—Cleavage not so perfect as the last ; parallel with the sides of the prism ; the larger angle $92^{\circ} 55'$; often in thick prisms ; usually associated with labradorite, never with orthoclase, nor with free quartz.

Talc Group.—Hydrous magnesian silicates.

Chlorite.—A hydrous silicate of alumina, magnesia, and iron. Usually granular, but sometimes in non-elastic flakes ; very soft, sectile, green, fusible ; in thin laminæ ; decomposed by concentrated sulphuric acid.

Serpentine.—A hydrous silicate of magnesia. Compact ; sometimes rather hard ; dark green, red, or brown ; almost infusible ; powder soluble in hydrochloric or sulphuric acid. Bright coloured and translucent varieties are called *precious serpentine*.

Talc.—A hydrous silicate of magnesia. Granular, or in thin non-elastic scales; very soft and sectile, and with a greasy feel; generally light coloured; infusible; not affected by acids.

Garnet Group.—Composition various, but all having the oxygen in the base equal to that in the acid.

Olivine.—A silicate of magnesia and iron. Yellow or olive-green; transparent or translucent; fusible with difficulty; easily decomposed by sulphuric acid; very characteristic of basalt.

Garnet.—A silicate of alumina, lime, iron, and manganese. Red, yellow, or brown; crystals rhombic dodecahedrons; fusible without much difficulty; generally found in the silicious rocks and mica schist.

CARBONATES.

(Effervesce with acids.)

Calcite.—Carbonate of lime. Crystals rhombohedrons; cleavage perfect; effervescence very brisk.

Dolomite.—Carbonate of lime with carbonate of magnesia. Crystals like the last; effervesces slowly, often only when scratched.

Gypsum.—Sulphate of lime, generally with water. Very soft, sectile; generally light coloured; very slightly affected by acids.

Rock-Salt.—Chloride of sodium. Soluble in water, and easily recognised by its taste.

CHAPTER III.

DENUDATION.

Denudation is the removal of solid matter by water in motion. Rocks gradually crumble away, partly by the mechanical action of rain and frost, and partly by combining with the oxygen of the air. Rain also, by means of the carbonic acid it contains, dissolves limestone, and the calcareous cement which often binds sand together. This is called the *weathering of rocks*.

Rain washes away the disintegrated rock, or *soil*, and carries it into the streams; the streams take it into the rivers, and the rivers take it into the sea. The atmosphere and the rain, therefore, are constantly decomposing the rocks, and carrying them down into the sea. This is called *subaerial denudation*.

The amount of material thus brought down annually by the Mississippi has been estimated at 7459 millions of cubic feet; by the Ganges at 6368 millions; by the Rhone at 600 millions; and by the Po at 1510 millions; while nearly an equal amount of carbonate of lime is probably brought down in solution by each river. Now, the areas of the drainage basins of these rivers are, in square miles: Mississippi, 1,147,000; Ganges, 432,000; Rhone, 25,000; and the Po, 30,000. If, therefore, we suppose the matter in solution to be equal to two-thirds of the solid matter brought down, and that the denudation is equally distributed over the whole area, we find that the Mississippi would lower its basin one foot in 4000 years; the Ganges one foot in 2240 years; the Rhone one foot

in 1020 years; and the Po one foot in 486 years. So that the average may be taken at one foot in 2000 years. Of course, denudation is not equally distributed over the whole area, but is much greater in some places than in others; the wear of the plains being probably only one-tenth of that of mountainous districts; still, the foregoing numbers give an approximate idea of the rate of sub-aerial denudation.

The sea also is constantly washing at the foot of cliffs, and reducing them to sand, which is swept away by the tides and currents. This *marine denudation* is more marked than the last, and we naturally fancy it to be doing a larger amount of work, but in reality it is not so. Marine denudation acts only along a narrow line, while subaerial denudation acts over the whole surface of the land; and while the latter is constant in its action, the former is fitful. The sea undermines a cliff, and landslips take place; then the whole of the debris has to be removed before the sea can again commence its undermining action.

It has been supposed that ten feet in a century is a very liberal average for marine denudation; although, of course, at some places it is far more rapid.

The solid matter brought down by rivers, or carried along by marine currents, is deposited when the movement of the water is checked, and thus gives rise to beds of clay or sand, which form the *inorganically derived sedimentary rocks*, so called because they owe their origin to inorganic sediments deposited in water.

But the matter held in solution by the rivers, which is chiefly carbonate of lime, is also distributed through the ocean, and is there seized upon by animals and plants, which again bring it back to the solid form, and when

they die, the calcareous matter they have secreted forms beds on the bottom of the sea, and gives rise to some of the *organically derived sedimentary rocks*.

By the term **Rock** geologists mean a mass of mineral matter of considerable size, consisting of many particles of one or more minerals, no matter whether it be hard or soft. Thus clay and sand are called rocks equally as much as granite or limestone. Three exceptions must, however, be made to this definition, viz., the surface soil; the detritus at the foot of a cliff, called a *talus*; and the deposits formed by rivers and glaciers in their valleys, called *river alluvia* and *moraines*. None of these deposits are called rocks because of their temporary character. The surface soil and taluses are constantly being taken down by the rain into the rivers; while alluvium owes its origin only to a temporary pause in the removal of matter from the land into the sea. When, however, the detritus is deposited by still water, either in a lake or in the sea, it then becomes a rock, because it has reached a more permanent position. In the first case it is a *marine*, in the latter a *lacustrine deposit*.

It has been already mentioned that rain-water dissolves limestone; this causes deep holes, called *swallow-holes*, to be formed in the surface of limestone districts; and the water running through fissures in the rock, gradually eats out long subterranean galleries, which, when exposed by subaerial denudation, form the caves so common in limestone. This may be called *underground denudation*.

When water containing carbonate of lime in solution evaporates, the carbonate of lime is again deposited in a solid form. Thus water dripping from the top of lime-

stone caves forms long, icicle-like pendants, called *stalactites*, and where the same water drops on to the floor of the cave it forms a crust called *stalagmite*.

CHAPTER IV.

FORMATION OF SEDIMENTARY ROCKS.

Formation of Sandstone and Slate.—It has been already mentioned that sedimentary rocks are formed by moving water washing away land, either from sea-cliffs or from river valleys, and depositing the sediment when quieter. This latter action is called *deposition*. The varying rate of movement in the water, caused by tides and floods, as well as the varying amount of matter held in suspension, cause these rocks to be deposited in an intermittent manner; and they are thus generally divided into thin layers, or *laminæ*, each of which, in its turn, has been the top of the bed. This division into thin layers by the process of formation is called *lamination*. These laminæ are sometimes differently coloured. It must be noticed, that not only is a certain amount of time necessary for the formation of each layer, but that the intervals between the layers represent time also. Lamination is very distinct in some fine-grained clays and slates, but in the coarser sandstones it can seldom be distinguished.

Planes of stratification are the divisions separating strata from one another; they differ from planes of lamination only in being on a larger scale; there has been a pause in the act of deposition, and sometimes a

complete change in the nature of the rock. Planes of stratification, therefore, mark a longer interval of time than planes of lamination. *Strata* or *Beds* vary from an inch to many feet in thickness.

From what has been said about the formation of these rocks, it is evident that they cannot be of indefinite extension, but must gradually *thin out*, as it is called, horizontally in all directions. They also vary considerably in thickness in different places.

The finer the sediment, the longer it takes to settle in water, and the wider it will necessarily be spread. Consequently we find that the finer the material of which a bed is composed, the greater generally is its extent, and the more equal is its thickness. Conglomerates, or beds formed of gravel, are the thickest and most irregular; slates or clays are the thinnest and most regular; while sandstones hold an intermediate position between the two.

The rate of deposition of clay in the deltas of large rivers has been estimated to be about one inch in five years, or sixty years to a foot; while sandstone is supposed to have been formed five times as fast, or twelve years to a foot; but very little is known on this head.

In geological sections conglomerates are usually represented by irregular circles; sandstones by dots; clays by fine lines parallel with the plane of stratification, or bedding; and limestones by distant lines parallel to the bedding, crossed by irregular lines at right angles to them.

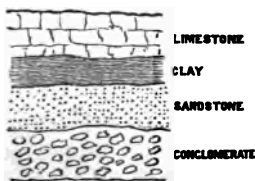


Fig. 1.

False Bedding, or Oblique Lamination.—We sometimes find a stratum of sandstone to be made up of laminæ lying obliquely to the planes of bedding, and these laminæ are constantly varying in their direction. This is called false bedding, and is caused by changes in the direction and strength of the current which is bringing down the material.

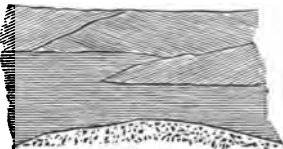


Fig. 2.

Swells or Rolls.—Sometimes a plane of stratification is interrupted by an upward swelling of the lower bed (see Fig. 2), called a swell or roll. These are owing to the upper bed having been deposited on the undulating surface of the lower bed. The stratum forming the swell is almost always of coarser texture than the one covering it.

Ripple-mark.—Sandstones are sometimes found with a crimped surface, like the ripple-mark seen on sandy beaches at low tide. Ripple-mark is formed in a direction transverse to the current, by the sand being pushed along the bottom; it is not, however, confined to the sea-beach, but has been known to form below the sea at a depth of 60 or 70, or even 300 or 400 feet. As a rule, however, it is characteristic of shallow water. Beach ripples are distinguished from current ripples by their frequent changes in direction. Ripple-mark is confined to sandstone; from it we can infer the direction and strength of the current.

Contemporaneous Erosion and Filling Up.—We sometimes find the upper surface of a bed of clay or silt much eroded, and even undercut in places, and the hollows filled up by sand, which is part of a stratum overlying the

clay. This is called contemporaneous erosion and filling up; it is especially characteristic of river alluvium.

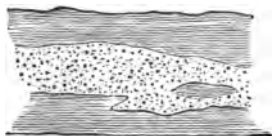


Fig. 3.

Intercalation of Beds.

— When a bed thins out, those lying above and below it must of course come together. The thinning-out bed (Fig. 4, B) is said to be intercalated between A and C. The plane of stratification,



Fig. 4.

therefore, between A and C marks an interval of time during which B was deposited,

but which, at that place, is quite unrepresented.

It must also be noticed that the deposition of B must have been finished before that of A commenced; consequently, if we wish to make an estimate of the time taken to form any group of beds, we must take the maximum thickness of each bed as our standard, and not the mean thickness of the whole group.

In the same way a group of beds may change their mineral character in a horizontal direction, one set of beds thinning out, and being gradually replaced by another set. The scale upon which these changes take place varies; sometimes it is completed in a few yards, while at others it is several miles before the change becomes apparent.

Change in the Lithological Character of Beds.—It has been already said that clays are formed by the finer material being carried farther than the coarser sand; consequently, we ought to expect to find one gradually changing into the other, and this we actually do. A sandstone may gradually change its

composition in a horizontal direction until it becomes a clay or slate, both parts of the bed being strictly contemporaneous. Sometimes also, but more rarely, a bed gradually changes its composition in a vertical direction, a sandstone gradually passing upwards into a clay or slate.

Sedimentary Rocks Originally Horizontal.—

From what has been said, it is evident that the sedimentary rocks, having been formed in still water, must originally have been horizontal, or nearly so; for the undulations and slopes of the sea-bed are very gentle, and the deposits would first fill up the hollows, and then spread horizontally over them. An exception must, however, be noted where streams fall into a lake or fiord with steep sides. Under these circumstances beds may be seen forming at angles of 20 and 30 degrees.

Formation of Limestone.—Although rivers are constantly bringing down carbonate of lime, and to a less extent carbonate of magnesia, into the sea, it is still far from being saturated with them, and, owing to currents, the composition of the water is remarkably uniform in all places; so that, except in salt lakes, no local deposit can take place. Before sea-water could deposit carbonate of lime, about three-quarters of it would have to be evaporated, but when rather more than a third had evaporated, sulphate of lime would be deposited; and this we never find in limestone. The sea also contains five times as much carbonic acid as is necessary for the solution of the carbonates contained in it, and the shells of animals would be dissolved, were it not that they are protected by animal matter.

Magnesian limestone is probably formed by the gradual evaporation of salt-water lakes, as it is almost always

accompanied by beds of gypsum and rock salt ; but ordinary marine limestone must have had an organic origin.

Limestones may be classed under two heads. One, of which chalk is the type, has been formed by the gradual deposition of the minute shells of the foraminifera on the bottom of a deep ocean far from land. The other, of which ordinary compact limestone is the type, has been formed by the breaking up of coral reefs either in mid-ocean or near the land. It is also possible that some limestones might have had a vegetable origin, for some plants, as the corallines, secrete carbonate of lime. Some also of the oldest limestones in Canada appear to have been built up by reef-building foraminifera instead of reef-building corals.

Coral Reefs consist in great part of a compact limestone, often containing shells or pieces of coral imbedded in it, but often also quite unfossiliferous. It is never earthy, like chalk. The action of the waves in breaking up the reef is necessary for the formation of limestone from corals, consequently its formation at great depths is impossible ; but as the land is often gradually sinking, great thicknesses can in time be built up, each part having in turn formed the top. Coral-reef rock is often stratified, and the beds are sometimes inclined to the horizon.

Modern deposits of carbonate of lime, whether formed in the atmosphere or beneath water, either fresh or salt, are indurated almost from the commencement of the deposition. Horsford ascribes the induration of the Florida Reef to the decomposition of the animal matter. Professor Dana thinks that the consolidation of coralline sand along the coast is due to the deposition of carbonate of lime between the particles in consequence of

evaporation ; while Bischof says that it is not improbable that the induration of chalk mud is gradually effected by the carbonate of lime dissolved in water. "It may be therefore that, as this goes on, the mass is converted into compact limestone." Changes are known to take place in carbonate of lime ; stalactites acquire in time an internal crystalline structure, and break into rhomboids. Oyster-shells are also known to have become crystalline.

It is estimated that corals grow at the rate of about a half to one and a half inches a year. This is about equivalent to three-eighths of an inch of solid limestone ; but as the corals are much broken up by waves, and widely spread by currents, Professor Dana thinks that the average upward increase of limestone would not exceed one-eighth of an inch a year, or seventy-two years to a foot.

Formation of Coal.—Coal consists principally of carbon, combined with small quantities of oxygen and hydrogen, and a varying amount of ash, which is made up of silica, alumina, and ferric oxide. Its vegetable origin is undoubted. Not only can we trace a complete series from plants through peat and lignite, to brown and black coal, but traces of vegetable tissue have been found in all qualities of coal.

When vegetable matter decays in the open air, the carbon unites with the oxygen of the air, and forms carbonic acid gas, which escapes ; and when the decomposition is over, hardly a trace remains behind. But when vegetable matter decays under water, the decomposition is much less complete, and a portion of the carbon remains behind ; consequently coal must have been formed under water, and we must look upon swamps as representing the original formation of all coal seams.

These swamps are known to be now forming on the banks and at the mouths of slow-running rivers, on the margin of lakes, and along the sea-shore ; the essential conditions being shallow water with a very slight current, and an abundance of perennial vegetation, consisting of trees, rushes, bog-moss (*sphagnum*), and other aquatic plants. Peat is also found in smaller quantities on mountains, where it is composed of bog-moss and grass.

Peat is found covering large areas in most temperate countries ; nearly the whole of Holland is covered by it. It is rare in the tropics, but is known to occur in India. Peat grows at the rate of about nine or ten feet in a century, but in the change into bituminous coal a loss occurs of about three-quarters of the whole, and there is also a reduction in bulk by compression ; so that it would probably take eight feet of vegetable matter, decomposing under water, to make one foot of coal, which would therefore be the production of eighty-four years' growth.

The vegetable matter is often mixed up with some mud, and the purity of the resulting coal would depend upon the relative proportions of the two. Coals are found of all qualities until they pass into bituminous or carbonaceous shale. Practically any rock that will make a fire without the addition of any other substance is called a coal.

CHAPTER V.

METAMORPHISM.

THE term *metamorphism* really includes all the transmutations or changes that have taken place in rocks since their formation, but in consequence of the name "metamorphic rocks" having been given to the crystalline schists, it has come to be applied by geologists to one particular kind of metamorphism only, while other kinds are called *consolidation*, *alteration*, and *decomposition*.

Pseudomorphism.—Water charged with carbonic acid has the power of dissolving many substances, and as these are dissolved, particles of some other mineral are often simultaneously deposited from the water in their places. This is called *replacement*. In this way we often find wood changed into silica, and fossil shells changed into silica or iron pyrites; they are then said to be *petrified*.

When minerals have been so changed—one mineral now occupying the place in a rock formerly occupied by another mineral—the newly-formed mineral is called a *pseudomorph*; and as the crystalline form of the removed mineral often reveals to us its composition, we are able to say what mineral has been removed and what deposited in its place. It is evident, therefore, that the study of pseudomorphs gives valuable information about the changes that have taken place in rocks.

Consolidation.—The pressure caused by the continual accumulation of matter squeezes the water out of a rock, even when it is under water, and tends to conso-

litate it; and it is quite possible that many clays and soft sandstones have never undergone any further hardening process. But usually as soon as a rock is raised above the sea-level, water containing silica, carbonate of lime, or ferric oxide, begins to percolate through it, and joins together the various particles into a hard rock by a silicious, calcareous, or ferruginous cement. This is called *infiltration*. Rocks therefore owe their hardness to compression and infiltration.

Metamorphism.—When the water percolating through rocks is heated and alkaline, it is much more powerful in effecting chemical changes, although its temperature may not be very high. Chemists consider that a temperature of from 212° F. to 480° F. would be quite sufficient for the formation of all minerals, and Dr T. S. Hunt says, that when alkalies are absent, metamorphism may fill slate with andalusite, kyanite, and other minerals, although it cannot produce felspar.

The first effect of this kind of metamorphism on rocks is to remove part of their water and oxygen, and to harden them. As it progresses, crystals are formed, each mineral crystallising separately, but having a tendency to arrange themselves in layers parallel to the bedding or cleavage of the rock. This gives rise to a fissile or *schistose* structure called *foliation*. The rocks thus metamorphosed are called the *crystalline schists*; and when the different minerals composing them are more or less perfectly separated into different layers, they are said to be *foliated*.

The origin of foliated structure is not well understood. Most geologists suppose that the water, percolating through either the planes of bedding or of cleavage, dissolves some minerals and deposits others; and they thus account for the foliation coinciding either with the

cleavage or with the bedding, or occasionally even with the false bedding of a rock. Others suppose that foliation is due to internal movements in the rock, induced by unequal pressures when it is in a semi-fluid state.

The amount of change effected in rocks varies very much according to their composition; felspathic rocks altering easiest, clays next, and sandstones and limestones least. Thus volcanic tuffs are easily changed into porphyry of different kinds; clays pass through slate into mica-schist and gneiss, while sandstone only changes into quartzite and quartz-schist, and limestone into granular limestone. Peat and lignite pass through coal into anthracite and graphite.

Alteration.—Metamorphism by dry heat also occurs where eruptive rocks come in contact with sedimentary rocks. In these cases the sedimentary rocks are usually hardened to a distance sometimes of several feet. Sandstone is changed into quartzite, and gets a columnar structure. Clay is converted into a flinty slate called *porcellanite*; while coal becomes hard and brittle, passing into a kind of anthracite or *blind-coal*, and near the dykes it is generally either powdery or cindery for a distance of 8 or 9 feet. The alteration of coal sometimes extends for 30 or 40 yards along the seam. The eruptive rock penetrating coal is generally as much altered as the coal itself, becoming earthy in texture and white in colour. Minerals are often developed in rocks bordering dykes, but no approach to a schistose or foliated structure has ever been observed.

Metamorphism in the dry way is, therefore, distinguished from that produced in the wet way by the very limited areas over which it acts; and it is usual to apply the terms *alteration* and *altered rocks* to changes produced

in the dry way, while *metamorphism* and *metamorphic rocks* imply changes produced in the wet way.

Decomposition.—The foregoing changes are all produced in the absence of atmospheric air; but when air is present another kind of metamorphism takes place, which is called *decomposition*, or *weathering*.

In this case the minerals composing the rocks are oxydised, and formed into hydrates; the rock disintegrates; the crystalline form is more or less destroyed, and an earthy texture assumed. It is, therefore, the converse of ordinary metamorphism.

The rapidity with which rocks decompose varies very much, and depends more upon their composition and texture than upon their hardness. Granites and other hard eruptive rocks often decompose faster than some soft clays.

CHAPTER VI.

DESCRIPTION OF SEDIMENTARY ROCKS.

THE sedimentary rocks owe their origin to deposition in water; they are usually made up of water-worn fragments, either small or large; they are never glassy, and never contain small rounded hollows. They are found in parallel beds or strata, and never send veins into other rocks. With the exception of the crystalline schists, they are generally fossiliferous.

They can be divided into two orders, which have an inorganic or organic origin respectively; and each order can be divided into two divisions, according to their chemical composition.

ORDER I.—INORGANICALLY DERIVED.**DIVISION I.—ARENACEOUS ROCKS.***Protomorphie Group.*

Sandstone.—Small rounded grains of quartz compacted into solid stone; generally yellow, brown, red, or green. S.g., 2.45–2.67. The green colour is owing to the presence of silicate of iron, the red to peroxide of iron. Red sandstones have generally a fresh-water origin, while green sandstones are invariably marine.

Argillaceous sandstone is a variety containing clay.

Calcareous sandstone is a sandstone in which the quartz grains are cemented together by carbonate of lime.

Micaceous sandstone contains flakes of mica parallel to the bedding.

Grit is a coarse variety of sandstone, with a sharp, gritty feel.

Conglomerate.—Consolidated gravel or shingle. The pebbles may consist of any substance; but quartz, on account of its hardness, usually predominates. The fragments are of all sizes, from a walnut to several feet in diameter, and are always water-worn, and rounded on the edges. If the edges are sharp, it becomes a *breccia*.

Sub-Metamorphic Group.

Quartzite.—Composed of grains of quartz fused together at their edges, not by heat, but by an infiltration of silica. It often contains some mica.

Metamorphic Group.

Quartz-Schist.—A schistose quartz rock, usually containing some mica.

Itacolumite.—A fine-grained schistose sandstone, with some mica and chlorite; in thin plates, sometimes flexible.

DIVISION II.—ARGILLACEOUS ROCKS.

Protomorphic Group.

Clay is a mixture of very fine grains of silica with silicate of alumina. S.g., 2-2.5. The silicate of alumina is derived from the decomposition of felspar. The amount of sand varies, but any earth that possesses sufficient ductility to be moulded when wet is called a clay. When still more sand is present, it becomes a *loam*.

Shale is a laminated variety of clay.

Bituminous shale is dark brown, and contains more or less carbonaceous matter.

Marl is a mixture of clay and carbonate of lime, the latter varying from 10 to 50 per cent.

Sub-Metamorphic Group.

Slate.—A compact, splintery, argillaceous rock, with an earthy fracture. Silica, 40-75 per cent. S.g., 2.5-2.8.

Common uncleaved slate is often called *argillite*, to distinguish it from *roofing slate*, which is the most perfectly cleaved variety of the rock.

Novaculite, or whetstone, is a very fine-grained, highly silicious slate.

Metamorphic Group.

This group contains nearly the whole of what are often called the metamorphic rocks or crystalline schists. They are all more or less schistose and foliated. All

these rocks are found very much mixed together, and the most prevalent variety is generally taken to represent the whole.

Phyllite, or Argillaceous Mica-Schist.—A schistose, slate-like rock, with minute flakes of mica. Silica, 45–75. S.g., 2·6–2·8.

Mica-Schist.—A crystalline schistose compound of quartz and mica. Silica, 69–82. S.g., 2·7–3·1. A very variable rock, often containing crystals of red or brown garnet; often corrugated, waved, or knotty.

Conglomerates sometimes occur among mica-schists.

Hornblende-Schist.—A schistose, or sometimes compact, rock, consisting chiefly of hornblende, with some felspar, quartz, or mica. Silica, 48–54. S.g., 3–3·1.

Chlorite-Schist.—A schistose rock, composed of chlorite and quartz, with occasionally felspar, mica, and talc. Silica, 31–42. S.g., 2·7–2·8.

Talc-Schist.—A schistose rock, composed of talc, with some quartz and felspar. Silica, 50–62. S.g., 2·6–2·8.

Gneiss.—A foliated crystalline-granular compound of quartz, felspar, and mica. Silica, 64–76. S.g., 2·6–2·7. Colour grey. The felspar is usually orthoclase, sometimes with oligoclase.

Granulite is a variety without mica.

Granitoid-Gneiss.—A crystalline-granular or irregularly foliated compound of quartz, felspar, and mica. Silica, 62–80. S.g., 2·6–2·7.

It is often impossible to tell hard specimens of this rock from true eruptive granite, and one passes gradually into the other. It is only by its geological position that it can be decided whether a rock should be called a granite or a granitoid gneiss.

ORDER II.—ORGANICALLY DERIVED.

DIVISION I.—CALCAREOUS ROCKS.

(All these rocks effervesce with acid.)

Protomorphic Group.

Limestone.—A crystalline-granular or earthy aggregate of calcite. S.g., 2·5–2·8. Effervesces strongly with acid; easily scratched with a knife.

Chalk is an earthy, friable variety, generally of a white colour. S.g., 2·5.

Crystalline limestone has a coarsely crystalline structure, often with numerous angular holes. S.g., 2·7.

Oolite is a limestone composed of small round concretions. S.g., 2·47.

Magnesian Limestone.—A more or less earthy aggregate of carbonate of lime and carbonate of magnesia; effervesces slightly with acid.

Sub-Metamorphic Group.

Compact Limestone.—A fine-grained smooth rock, with an earthy, splintery, or conchoidal fracture.

Dolomite.—A granular, more or less compact aggregate of carbonate of magnesia and carbonate of lime. S.g., 2·8–2·9. Effervesces very slightly with acid.

Metamorphic Group.

Granular Limestone.—A granular, sometimes schistose, aggregate of crystalline particles of calcite, often containing mica, garnet, &c. S.g., 2·7.

Ophicalcite, or Verde-Antique.—A granular or compact compound of limestone and serpentine.

DIVISION II.—CARBONACEOUS ROCKS.

These rocks are all dark-coloured, and have a small specific gravity.

Protomorphic Group.

Peat.—An aggregate of vegetable growth, more or less compressed and decomposed.

Lignite.—A brown compact or earthy mass, showing in places the texture of the wood contained in it.

Brown Coal.—A brown or black compact mass. Fracture shaly or conchoidal; streak brown; falls to pieces on exposure to the air, owing to the quantity of water it contains.

Sub-Metamorphic Group.

Pitch Coal, or Cannel Coal.—A compact dull or shining mass; fracture shaly or conchoidal; streak black; not dirty to touch.

Black Coal, or Common Coal.—A black compact shining mass; fracture uneven or shaly; streak black; does not fall to pieces on exposure; generally dirty to touch.

Caking coal fuses together when burning, while *Cherry coal* does not cake. *Splint coal* is very hard and firm, and is difficult to light.

Metamorphic Group.

Anthracite.—Black, friable, with a vitreous or semi-metallic lustre; streak black.

Graphite, or Plumbago.—A greyish-black, soft mass, with a greasy feel; dirty to touch; not inflammable; streak black.

SEDIMENTARY ROCKS.

	ORDER I. INORGANICALLY DERIVED.		ORDER II. ORGANICALLY DERIVED.	
	<i>Division I.</i> Arenaceous Rocks.	<i>Division II.</i> Argillaceous Rocks.	<i>Division I.</i> Calcareous Rocks.	<i>Division II.</i> Carbonaceous Rocks.
PROTO-MORPHIC GROUPS.	Sandstone. Conglomerate.	Clay. Marl.	Limestone. Magnesian limestone.	Peat. Lignite. Brown coal.
SUB-META-MORPHIC GROUPS.	Quartzite.	Slate.	Compact limestone. Dolomite.	Pitch coal. Black coal.
META-MORPHIC GROUPS.	Quartz- schist. Itacolumite.	Phyllite. Mica-schist. Hornblende- schist. Chlorite- schist. Talc-schist. Gneiss. Granitoid- gneiss.	Granular limestone. Opicalcite.	Anthracite. Graphite.

CHAPTER VII.

POSITION OF STRATA.

ALTHOUGH, as has been stated, the sedimentary rocks were originally formed in a horizontal position, we now find them inclined at all angles to the horizon.

The angle that the plane of stratification makes with the horizon ($\angle A B C$, Fig. 5) is called the *dip*, and a line at right angles to the direction of the dip is called

the *strike*. The strike is therefore independent of the amount of dip; and with the same strike beds may dip in exactly opposite directions. Thus with a N. and S. strike the beds may dip either E. or W., and it is immaterial at how great or small an angle they dip. If, therefore, we know the dip of a bed, we can find its strike; but if we know the strike only, we do not necessarily know the dip.

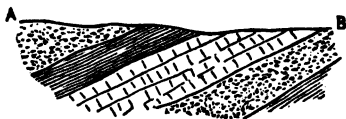


Fig. 5.

When a bed comes to the surface it is said to *crop out* at that place, and the line along which it crops out is called the *line of outcrop*. If an inclined bed crops out on a horizontal plain, its line of outcrop will coincide with its strike; but if it crops out on a slope, the two will not coincide, unless the bed is vertical.

When strata are thrown into folds, alternately rising and falling, those lines from which the beds dip away on

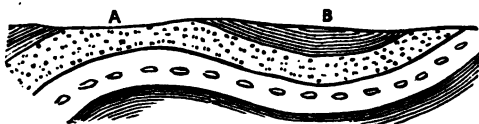


Fig. 6.

either side (Fig. 6, A) are called *anticlinal axes*, while those lines towards which the beds dip from either side (Fig. 6, B) are called *synclinal axes*; and the strata are spoken of as forming *anticlinal and synclinal curves*. An anticlinal or synclinal axis may be horizontal, or, as is more usual, it may be inclined at any angle with the horizon.

When the longitudinal axes of anticlinal or synclinal

curves are short, the strata form what are called *dome-shaped elevations* and *basin-shaped depressions*.

When horizontal strata bend down in one direction, and do not come up again, it is called a *uniclinal curve* (Fig. 7.)

When anticlinal and synclinal curves occur frequently, and on a small scale, especially when the anticlinal and synclinal axes are not



Fig. 7.

parallel, the position of the beds becomes very complicated, and they often appear to be twisted in an extraordinary manner. Such complicated foldings are called



Fig. 8.

contortions (Fig. 8.) Contortions are also often caused by the major anticlinal and synclinal folds being crossed by minor folds, which may have their axes parallel to those of the major folds, or at right angles to it, like a corrugated iron roof, or in any intermediate position. It will be readily understood that these complex folds make it very difficult to work out accurately the geological structure of a contorted district.

Sometimes the folding of the beds is carried so far that one side of an anticlinal or synclinal curve is completely overturned, so that the lower and older beds lie on the younger ones. This is called *inversion*.

Anticlinal and synclinal curves and contortions are caused by great lateral pressure, combined with a consi-

derable but less vertical pressure; and for the same amount of lateral pressure the foldings will be more or less numerous, according as the vertical pressure (or weight of the superincumbent rocks) is greater or less, and the rocks themselves are less or more rigid. A very large amount of bending, however, can take place in hard rocks without fracture, provided that the pressure is very gradually increased, and the movement is very slow.

Unconformity.—When the base of one set of beds rests in different places on different parts of another set of beds, the two are said to be *unconformable* to each other; or an *unconformity* is said to exist between the two. The simplest case of unconformity is when the two sets of beds dip at different angles and in different directions.

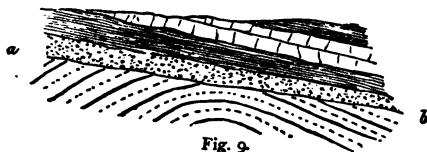


Fig. 9.

Unconformity may, however, exist when the dip of both sets of beds is the same, extensive denudation having so worn down the upper surface of the lower set of beds that the base of the upper set rests in different places on

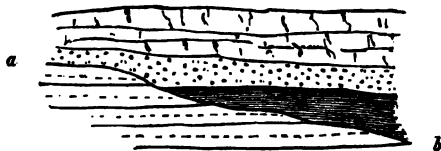


Fig. 10

different parts of the lower set. Unconformity between two sets of beds is often much more easily recognised on a geological map than in sections.

Overlap.—When the upper beds of a perfectly conformable series extend over a wider space than the lower beds, the upper beds are said to overlap the lower (Fig. 10).

CHAPTER VIII.

VOLCANIC ACTION.

Paroxysmal Eruptions.—A volcano is a more or less conical hill or mountain, composed of materials that have been ejected from beneath the surface. These eruptions almost always occur at irregular intervals, varying from months to centuries; they are generally violent in character, and of but short duration; they are therefore called *paroxysmal eruptions*. When the periods of inactivity are short, the volcano is said to be *active*; when very long, it is said to be *dormant* during those periods; when the volcanic activity has altogether ceased, it is said to be *extinct*.

A new volcano broke out in Nicaragua in November 1867; the eruption lasted for sixteen days, and a cone 200 feet high was built up. Vesuvius was dormant for more than 700 years previous to the eruption of A.D. 79, which buried Herculaneum and Pompeii; while Stromboli has been in incessant activity ever since the days of Homer.

A paroxysmal eruption is generally preceded by earthquakes and loud noises like cannon; explosions then follow, which hurl into the air fragments broken off the top of the mountain. Huge quantities of steam are at the same time discharged, which form a white column issu-

ing from the top of the mountain, sometimes more than a thousand feet high. During this time the lava continues to rise, until it either forces an opening through the side of the cone, or flows over the lower part of the orifice. Volumes of steam rise from the lava and form clouds round the mountain. The appearance of the lava generally marks the crisis of the eruption, after which the explosions gradually decrease in violence, and the eruption terminates. It is now seen that the top of the mountain has been blown off, and a large chasm formed in its place.

Some of the more liquid portions of lava shot up assume a pear-shaped form by being twirled through the air, and are called *volcanic bombs*; the greater part, however, cooling rapidly in the air, are reduced to cellular scoriæ, and fall in showers of ashes round the mountain, thus giving it its conical shape. These showers of ashes, when they fall into the sea, form rocks called *tuffs* or *tufas*, which are regularly bedded, and often enclose fossils. When many of the fragments are of large size, the rock is called a *volcanic agglomerate*.

The smaller eruptions generally build up cones with a

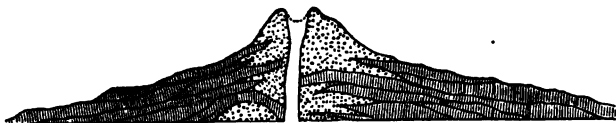


Fig. 11.

central funnel-shaped hollow, called a *crater*, on the top, while the larger ones scatter the ashes round the base of the mountain, where they are consolidated by the lava which flows over them, and is injected into the fissures which traverse the mountain in all directions, forming

what are called *dykes*. These dykes are often seen to send out small *veins* into the neighbouring rocks.

The *gases* that escape from a volcanic vent are chiefly steam, sulphuretted hydrogen, and sulphurous acid, but the steam forms '99' of the whole.

Lava, when first erupted, is a semi-fluid mass at a white heat. It is very stiff and tenacious, so that it requires some force to thrust an iron rod into it; but the amount of fluidity varies considerably. The surface rapidly cools into a slag, which is so bad a conductor of heat that it may be stepped upon while the stream is still in motion. From this cause the internal mass often remains hot for many years. Lava generally moves slowly, and has been known to be in motion nine months after its eruption. It is this movement, after the crust has become solid, that causes the roughness of the surface of lava streams. Occasionally the interior part flows out, leaving the crust standing as an arch, thus forming a cave. Lava flows into water without occasioning any great commotion, the superficial consolidation that instantly ensues preventing further contact with the heated interior.

Lava cools down into rocks called *basalt*, *trachyte*, &c., according to its chemical composition.

An examination of the products emitted during paroxysmal eruptions shows that they are, partly at least, composed of materials belonging to the surface which have become engulfed. Thus Abich says that the eruptive mass of Monte Nuovo is nothing but the scorïæ of the Phlegræan Fields remolten, and that the modern products of Vesuvius appear to be but a *rechauffée* of the lavas of Somma with the addition of soda.

When the subterranean heat has become too weak to maintain the mineral masses in a state of fusion, the

volcano gives off acid fumes, which deposit sulphur and saline incrustations on the rocks; it is then called a *Solfatara*.

Mountains which owe their origin to paroxysmal eruptions are composed of alternating beds of ashes or scorix and sheets of lava, seldom very thick, inclined at small angles with the horizon, and having a more or less radiating structure.

Massive Eruptions.—But in many parts of the world we find long narrow ranges of mountains composed of volcanic rocks, which are compact, of great thickness, without showing any horizontal structure, containing no scorix; and when planes dividing dissimilar rocks are seen, they are inclined at all angles to the horizon. Broken angular fragments, forming breccias, are common in the rocks, but these breccias assume no regular shape. Volcanoes often occur on the lower portion of their slopes, but the high ranges show no signs of any craters. These are called *massive eruptions*. Their origin is not accurately known, for nothing of the kind has ever been observed in the act of formation; but they have probably been formed by the slow welling out of pasty lava from fissures under deep water, the pressure of which prevented any steam being formed.

Paroxysmal eruptions are marked by agglomerates, tufas, and lava flows.

Massive eruptions are marked by breccias and massive accumulations. All the rocks mentioned in this chapter as having been formed by volcanic action are called *eruptive rocks*, because they have broken out from below the surface, and have been forcibly erupted amongst the sedimentary rocks.

CHAPTER IX.

DESCRIPTION OF ERUPTIVE ROCKS.

THE *composition* of a rock refers to the mineral substances of which it is composed, while the *texture* of a rock refers to the arrangement of the particles composing it.

When the minerals are crystallised, the rock is said to be *crystalline* if the crystals can be seen by the naked eye, or *crypto-crystalline* if a microscope is necessary to see them. If distinct crystals of one or more minerals are imbedded in a crypto-crystalline paste, the texture is said to be *porphyritic*, and the rock is called a porphyry. If the minerals are all fused into a glass-like mass, the texture is called *vitreous*.

When the crypto-crystalline and vitreous rocks are solid throughout, they are said to be *compact*; when they are full of little rounded hollows, they are said to be *vesicular*. When these hollows have been filled up with minerals, the rock is called an *amygdaloid*. These different textures depend upon the different circumstances under which the rocks have cooled. The crystalline rocks have cooled slower than the crypto-crystalline and vitreous; and the compact rocks have consolidated under greater pressure than the vesicular ones, the vesicles being caused by the expansion of gases, such as aqueous vapour, in the rock when the pressure was reduced.

The eruptive rocks owe their origin to fusion; they are often porphyritic, vitreous, or vesicular, and only

exceptionally contain water-worn fragments. They are principally composed of silicates, and never contain carbonates as essential constituents. They are found cutting across the bedding of other rocks, and sending veins into them. With the exception of the tuffs formed by volcanic eruptions, they are always non-fossiliferous, and either massive—that is, not divided into distinct beds—or the beds are local and irregular.

They can be divided into three orders, according to their chemical composition, distinguished principally by the amount of silica they contain; and these orders can be divided into different groups, according to the texture of the rock.

ORDER I.—SILICIOUS ROCKS.

Always light-coloured, except the vitreous group; almost always contain free quartz; generally weather-white. Silica, 65–80 per cent. S.g., 2.5–2.7; of the glass, 2.3–2.4.

Crystalline Group.

The rocks belonging to this group are readily distinguished from all others by the quartz generally permeating the interstices between the other minerals; they are often called the *granitic rocks*, and are usually massive, covering large areas of ground, but sometimes occur as dykes.

Granite.—A crystalline granular compound of felspar, quartz, and mica. Silica, 66–80. S.g., 2.6–2.7.

The felspar is chiefly orthoclase, often accompanied by oligoclase; the orthoclase is usually opaque, yellowish white, red, or greyish.

Pegmatite is a coarse variety, composed of orthoclase, quartz, and silvery-white mica.

The term granite was first scientifically defined by Werner.

Syenitic-Granite.—A crystalline granular compound of felspar, quartz, and hornblende. Silica, 64–72. S.g., 2·6–2·7.

Syenitic-granite often contains some mica, and thus passes gradually into granite; the quartz sometimes diminishes in quantity, and the rock then passes into syenite.

Porphyritic Group.

Quartz - Porphyry.—A compact quartzo-felsitic matrix, enclosing crystals or crystalline grains of quartz, and orthoclase or oligoclase. Silica, 70–80. S.g., 2·5–2·6. Occurs massive or in dykes.

Liparite.—A compact quartzo-felsitic matrix, enclosing crystals or crystalline grains of quartz, and sometimes oligoclase, sanidine, and biotite. Silica, 67–80. S.g., 2·4–2·6.

This rock is often called *trachyte-porphyry*; it generally occurs massive, but occasionally as the product of paroxysmal eruptions.

Some varieties much resemble granite or syenitic-granite.

Crypto-Crystalline Group.

Felstone.—Compact, dull, light-coloured; sometimes fissile. Silica, 70–80. S.g., 2·5–2·7.

Occurs massive or in dykes; it is an intimate mixture of felspar and quartz, and may be considered as granite in a compact state.

Vitreous Group.

Rhyolite.—A variously-coloured (black, brown, red, or yellow) vitreous mass, sometimes enclosing crystals of sanidine, oligoclase, mica, or quartz. Silica, 67–80. S.g., 2·3–2·4. Often contains round balls of felsite, sometimes with concentric layers, called sphaerolites; the rock is then called *perlite*. *Obsidian* is a black variety. *Pumice* is a highly vesicular state of the same rock. The older rhyolites are called *pitchstone*.

Rhyolite generally occurs as a product of paroxysmal eruptions, but occasionally massive. The name was introduced by Baron Richthofen.

Fragmental Group.

Felsite Tuff, or Felspathic Ash.—Compact, fracture earthy, often variegated; stratified; sometimes fossiliferous.

Pumice Tuff, or Trass.—Yellowish white, or grey; earthy, rough; composed of small particles of pumice; sometimes fossiliferous. Much of this tuff appears to be the product of volcanic mud-streams.

ORDER II.—FELSPATHIC ROCKS.

Grey, greenish, or blackish; rarely contain free quartz. Silica, 50–65 per cent. S.g., 2·3–3·0.

Crystalline Group.

Syenite.—A crystalline granular compound of orthoclase and hornblende. Silica, 55–60. S.g., 2·7–2·9. Reddish or white, with black specks. Some syenites con-

tain, in addition, oligoclase, and thus pass into diorite. Syenite has usually a coarser texture than diorite.

Usually massive, sometimes in dykes ; often associated with granite.

The term syenite was first scientifically defined by Werner.

Porphyritic Group.

Porphyrite, or Felspar Porphyry.—A compact, generally dark, felsitic matrix, enclosing crystals of oligoclase, and sometimes mica or hornblende. Silica, 59–61. S.g., 2·6–2·7. Crystals of orthoclase also occasionally occur, but never of quartz.

Generally found in dykes, rarely massive.

The name was introduced by Naumann.

Trachyte.—A rough felsitic matrix, enclosing crystals of vitreous oligoclase, sanidine, and hornblende, with occasionally some augite and black mica. Silica, 60–65. S.g., 2·4–2·7. The matrix is generally vesicular, and never contains free quartz. It is light grey, reddish, or reddish brown.

Found chiefly as lava flows. The name was first introduced by Haüy.

Propylite, or Greenstone-Trachyte.—A compact felsitic matrix, enclosing crystals of hornblende and crystals or rounded grains of oligoclase ; the former dark green, the latter white or light green. Silica, 50–65. S.g., 2·3–2·7. Generally green, but sometimes grey or greenish brown. The oligoclase is never vitreous, as in trachyte. Some varieties contain augite in addition, but rarely mica. *Timazite* is a variety containing crystals of black hornblende.

The name propylite was introduced by Baron Richthofen. It generally occurs massive, but sometimes in

dykes. The Cornstock lode in California, as well as the gold and silver mines in Hungary, Transylvania, Auckland (New Zealand), Mexico, and probably Bolivia, are all situated in propylite.

Andesite.—A dark-coloured compact or vesicular matrix, with small crystals of oligoclase, and generally hornblende or augite. Silica, 50–65. S.g., 2·6–2·7. Bluish or brownish black to dark grey, rarely green; weathers reddish brown. The hornblendic variety is distinguished from melaphyre by its vesicular texture. The augitic variety sometimes contains olivine.

Generally occurs massive, but sometimes in dykes. The name was introduced by Leopold von Buch. It forms a large part of the Andes.

Crypto-Crystalline Group.

Phonolite.—Compact, rather dark greenish grey; sometimes fissile. Silica, 50–65. S.g., 2·4–2·6. Weathers white or reddish white.

Massive, or as lava flows. The name was introduced by Klaproth.

Melaphyre.—Compact; greenish or brownish black. Silica, 54–62. S.g., 2·6–3. Weathers reddish brown; never vesicular, and never containing olivine.

Occurs only as dykes. The name was introduced by Brongniart.

Fragmental Group.

Trachyte Tuff.—Matrix white, yellow, or greyish, with pieces of sanidine, hornblende, and occasionally garnet. Trachyte agglomerate and breccia are also found.

Propylite and Andesite also often form breccias, but never tuffs.

ORDER III.—PYROXENIC ROCKS.

Dark coloured, and never contain free quartz; always weather red. Silica, 40–55 per cent. S.g., 2·7–3·2; of the glass, 2·7.

Crystalline Group.

Greenstone.—A crystalline granular compound of triclinic felspar and hornblende or augite. Silica, 43–50. S.g., 2·6–2·9. Dark green.

The hornblendic variety is called *diorite*, and the augitic variety *diabase*; the latter contains some chlorite, and is generally of a brighter green than diorite, which is occasionally black-and-white speckled.

Occurs only as dykes. The name diorite was introduced by Haüy, and diabase by Hausmann.

Dolerite.—A crystalline granular compound of labradorite and augite with titaniferous iron. Silica, 42–55. S.g., 2·7–2·9. Dark grey to black; contains occasionally hornblende, olivine, and black mica.

The name was introduced by Haüy. The fine-grained varieties are called *anamesite*, a name introduced by Leonhard. It occurs either as dykes or lava flows.

Porphyritic Group.

Aphanite.—A compact dark-green or black matrix, enclosing crystals of augite and Labradorite or oligoclase. Silica, 42–55. S.g., 2·6–2·9. Generally contains titanic iron; often vesicular.

Occurs as dykes and lava flows.

Crypto-Crystalline Group.

Basalt.—Compact or vesicular; dark grey to black; generally containing olivine. Silica, 40-55. S.g., 2.9-3.1. Composed essentially of labradorite and augite with titaniferous iron.

Occurs as dykes and lava flows.

Vitreous Group.

Trachylite.—Vitreous, black, with the same composition as basalt. S.g., 2.7.

Occurs only on the sides of basalt and dolerite dykes.

Fragmental Group.

Greenstone Tuff.—A compact mass of particles of greenstone; generally green, but sometimes grey or brownish green; often fossiliferous. When it contains large masses of greenstone, it becomes a *greenstone agglomerate*.

Basalt Tuff.—Small fragments of basalt in a brownish paste. When the fragments are of large size, it is called *basalt agglomerate*.

Palagonite tufa is a yellow or blackish-brown variety resembling pitch, and with a conchoidal or splintery fracture.

NOTE.—**Serpentine** has been described as a mineral, but it usually occurs as a rock. It is generally a metamorphosed greenstone or syenite, but is sometimes formed from other rocks, such as hornblende-schist, in which case it forms a *serpentine-schist*.

Older and Newer Eruptive Rocks.—The erup-

tive rocks can also be divided into older and newer series (see table); but it is a disputed point among geologists whether the difference between the two is owing to an original difference in the rocks erupted at different periods of the earth's age, or whether it is owing to the subsequent metamorphism of the older eruptive rocks.

Determination of Eruptive Rocks.—A chemical analysis of a rock will generally point out the order to which it belongs, by giving us the percentage of silica that it contains; and an examination of the texture will show with which group it should be arranged. To ascertain the correct name of a rock, the different minerals composing it must be ascertained. If the separate minerals are large, they can be examined, tested by the blow-pipe and acid, and, if necessary, analysed. If, however, the component minerals are too small to be recognised by the eye, thin transparent slices must be made, and examined with a microscope. This enables the forms of the minerals to be seen, and their optical properties tested by polarised light, by which means many minerals can be distinguished from each other.

Few rocks can be considered as correctly named until they have undergone both a chemical and microscopical investigation.

ERUPTIVE ROCKS.

GROUPS ACCORDING TO TEXTURE.	ORDER I. SILICIOUS ROCKS. <i>65 to 80 p. c. of Silica.</i>	ORDER II. FELSPATHIC ROCKS. <i>50 to 65 p. c. of Silica.</i>	ORDER III. PYROXENIC ROCKS. <i>40 to 50 p. c. of Silica.</i>
CRYSTALLINE.	Granite. Syenitic- Granite.	Syenite.	Greenstone. Dolerite.
PORPHYRITIC.	Quartz-Por- phyry. Liparite.	Porphyrite. Trachyte. Propylite. Andesite.	Aphanite.
CRYPTO- CRYSTALLINE.	Felstone.	Phonolite. Melaphyre.	Basalt.
VITREOUS.	Rhyolite.		Trachylite.
FRAGMENTAL.	Felsite Tuff. Pumice Tuff.	Trachyte Tuff. Propylite Breccia. Andesite Breccia.	Greenstone Tuff. Basalt Tuff.

OLDER ERUPTIVE ROCKS.		NEWER ERUPTIVE ROCKS.	
Granite. Syenitic- Granite. Quartz-Por- phyry. Felstone. Rhyolite.	Syenite. Porphyrite. Melaphyre. Greenstone. Dolerite. Aphanite.	Liparite. Rhyolite. Trachyte. Propylite. Andesite.	Phonolite. Dolerite. Basalt. Trachylite.

CHAPTER X.

MODE OF OCCURRENCE OF THE OLDER ERUPTIVE ROCKS.

THE mode of occurrence of the older eruptive rocks, or, as they are sometimes called, the *trap* and *granitic rocks*, is similar to that of the newer eruptive or *volcanic rocks*, as described in Chapter VIII., with, however, this difference, that the enormous denudation which has taken place since the older rocks were erupted has removed the scoria cones and the greater part of the superficial accumulations, while it has displayed to view the underground portions of the old volcanoes.

These older eruptive rocks may be conveniently divided into those which are *contemporaneous*, or interbedded with the sedimentary rocks amongst which they occur; and those that are *intrusive*, or subsequent to the rocks among which they are found.

Contemporaneous Eruptive Rocks.—Tuffs and agglomerates of greenstone and felstone often occur; they have generally a more crystalline or porphyritic texture than the newer tuffs, but can usually be recognised not only by their being interstratified with sedimentary rocks, but by their included fragments of rock, and occasionally by containing fossils. A microscopical analysis will always show their true nature. Bombs have occasionally been found embedded in rock; they are always composed either of dolerite or melaphyre.

Tuffs are often more or less mixed with sand or clay, and may pass horizontally or vertically into sandstone or slate.

Old lava flows, generally called *sheets*, are often found parallel with the bedding; they are usually vesicular, and the upper surface is often very uneven, the cracks being filled with sand or clay from the overlying rock; they are sometimes found in a series, with agglomerates or tuffs between them. Submarine lava sheets may be recognised by the absence of vesicles.

Sheets are generally formed by the pyroxenic rocks; quartz-porphry and felstone, on the contrary, often form huge "hill ranges" contemporaneous with the sedimentary rocks, and are thus analogous to the massive eruptions described in Chapter VIII.

Intrusive Eruptive Rocks.—These are generally more coarsely crystalline than the contemporaneous

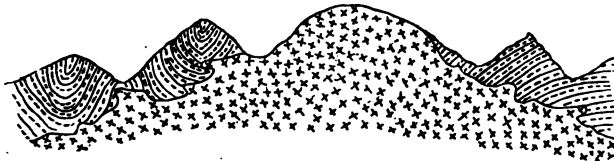


Fig. 12.

division. Granite and syenite usually occupy irregular areas of considerable extent, and this is especially the case with granite. Syenite often occurs on the outskirts of a granitic district. The sedimentary rocks do not always dip away from granite, but just as often straight into it, the granite appearing to have eaten its way through them. They always end abruptly against the granite, and are penetrated by veins from the eruptive rock. They are generally broken and altered near the point of contact, and the granite itself generally changes its character.

Granite is usually surrounded by the crystalline schists, but often slate is found in contact with it.

No great mass of any other rock is known to underlie intrusive granite, but dykes of greenstone traverse it in some places in Ireland, and basalt has been erupted through it in central France.

Dykes.—Quartz-porphry, porphyrite, melaphyre, greenstone, and dolerite often occur in tabular masses called dykes, which cut across the bedding of the sedimentary

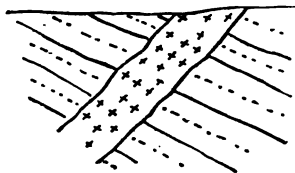


Fig. 13.

rocks. Felstone is more commonly found in narrow wavy irregular bands called *veins*. Dykes may send out veins, but generally veins occur only in connection with large intrusive masses.

Dykes vary in thickness from less than a foot to many yards, and have occasionally been traced for fifty or sixty miles. Their sides are generally very even and parallel.

Sometimes a band of breccia is found on one or both sides of the dyke, between it and the containing rock. These are generally local, and are called *friction breccias*. They probably owe their origin to the shrinkage of the dyke on cooling, causing a space to be left between it and the enclosing rock, which space was filled up by broken portions falling in. Occasionally a dyke is double, owing to two injections at different times.

The internal portions are generally more crystalline than the sides, and dolerite dykes are sometimes coated with trachylite.

Necks.—Sometimes the older eruptive rocks occur in cylindrical masses called necks. These necks may con-

sist of syenite or other crystalline rock, or they may be entirely formed by agglomerate. The beds surrounding these rocks are always much altered in appearance, and they sometimes dip towards the neck. They vary from a few feet to two or three hundred yards in diameter. Necks, although themselves intrusive, are almost always associated with interbedded eruptive rocks. They are evidently the pipes of old volcanoes.

CHAPTER XI.

STRUCTURE OF ROCK MASSES.

Joints.—Almost all rocks are traversed in various directions by smooth-sided fissures called *joints*. Sometimes two sets of joints run at right angles to each other, sometimes three or more sets divide the rocks into rectangular or irregular rhomboidal masses, the joints of each set being almost always parallel. When one set of joints are much larger than the others, and run parallel for long distances, they are called *master-joints*. If it were not for the joints, it would be almost impossible to quarry hard rock, but by taking advantage of them large blocks are got out with ease.

In fine-grained rocks joints are generally close and regular, but in conglomerates they are often open and irregular. In hard conglomerates the joints pass straight through the pebbles, one half-being seen on one side of the joint, and the other half on the other side.

Joints are caused by the contraction or shrinking of the rock when drying or cooling, in the same way that clay or mud cracks when dried. They are often very

difficult to distinguish from planes of stratification or bedding, especially in a quarry or unweathered surface. This difficulty does not generally occur with rocks on the sea-shore, owing to the different rocks weathering differently, and thus rendering the true bedding more apparent.

Prismatic jointing, or columnar structure, is most common in eruptive rocks, especially in basalt; but it is also found in sandstone that has been acted upon by heat. The columns always occur at right angles to the cooling surface, that is, in the direction in which cooling has taken place most rapidly. They are caused by the heated rock cooling first on those surfaces where it is in contact with the cold rocks through which it has been erupted. This cooling contracts the rock, which splits into irregular polygons on the surface. As the cooling

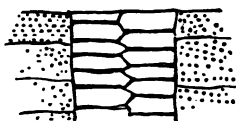


Fig. 14.

proceeds, the cracks formed on the surfaces are gradually prolonged inwards until they meet in the middle of the dyke. Sometimes the cracks on either side join each other, and columns are formed right across the dyke; at other times, the opposite cracks do not join, and the columns are separated in the middle.

If the dyke, or lava stream, is very thick, the transverse contraction is also sometimes sufficient to produce fissures parallel to the cooling surfaces which cross the columns, and divide them into separate pieces. On these being exposed to the air, weathering takes place more rapidly along the divisional planes than on the more solid parts, and thus gives rise to the appearance called *cup-and-ball structure*, or *articulated columns*. The columns are more regular in basalt than in other rocks, on account

of its greater homogeneity, and perhaps also its higher temperature.

Faults.—When the rocks on one side of a fissure have been moved more than those on the other side, the fissure is then called a fault.

Faults are sometimes vertical, but more often inclined. The sides of

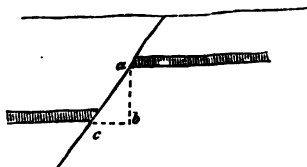


Fig. 15.

vertical faults are generally separated several yards, but inclined faults are almost always closed.

An inclined fault always dips to the down-throw, that is, towards the side on which the rocks stand at a lower level. This causes the rocks to be pushed apart horizontally, so that no portion of a bed can ever be brought by a fault vertically under another portion.

The amount of dislocation measured in a vertical direction is called the *throw* of the fault (Fig. 15, *a b*); while the amount of dislocation measured in a horizontal direction is called the *dead ground* (Fig. 15, *b c*). The throw and dead ground often vary in different parts of the same fault. The beds on either side of a fault may dip in the same direction, or the formation of the fault may have given them different dips. On approaching a fault, the beds on the down-throw side often rise to the up-throw, while on the other side they dip to the down-throw; but cases of the exact opposite are known. These are probably owing to folds in the rock anterior to the formation of the fault. Faults are caused by the contraction of the rock, and prove therefore that they have undergone tension.

Cleavage.—By the term cleavage, or *slaty-cleavage*, is

meant a tendency of certain rocks to split in very thin plates in a particular direction, quite independent of the original bedding of the rock. It is only found in contorted districts, and is confined to rocks that have undergone considerable pressure and metamorphism. Cleavage is best marked in slate, but it is sometimes seen in an imperfect form in sandstones, limestones, and even conglomerates. As a rule, the coarser the grain of the rock the fainter and wider apart are the cleavage planes. In traversing conglomerates, the cleavage planes leave the pebbles standing out, and do not cut through them as joints do.

The angle of inclination or dip of cleavage planes is generally high, and the direction of the strike is generally constant over large areas, no matter how much the bedding may vary. This direction usually coincides with the



Fig. 16.

axis of elevation of the district, and consequently with the average strike of the beds. Fossils are distorted by cleavage, and are drawn out in the direction of the planes sometimes to twice their original length.

Slaty-cleavage is due to great compression of the rocks at right angles to the cleavage planes squeezing flat the particles composing the rock, and causing them to slide laterally over each other ; thus producing planes of weakness. It must not be confounded with the cleavage of minerals, which is owing to a totally different cause.

Slikensides are polished striated surfaces of rock, often coated with silica, carbonate of lime, or hæmatite.

They are found running in all directions, and are especially common on the sides of joints or faults. Formerly they were considered as being due to movements of the rock, one piece rubbing against another; but many of them are now attributed to the crystallisation of minerals in parallel fibres.

CHAPTER XII.

MOVEMENTS OF THE SURFACE OF THE EARTH.

In Chapter IV. it was shown that all the sedimentary rocks were formed under the sea; but as we now find the larger portion of the land composed of them, it is evident that either the land has been raised above the sea, or the level of the sea has been lowered.

We have evidence in many parts of the world that the land has been elevated or depressed during earthquakes. In 1819 part of the delta of the Indus subsided from 2 to 8 feet, and the fort and village of Sindree were submerged. During the earthquake in Chili in 1835 the land was elevated suddenly 4 or 5 feet, and then gradually subsided again for about 2 feet. In 1855 an earthquake, which occurred on both sides of Cook Straits in New Zealand, was caused by the raising of the Rimutaka Mountains in the north island for 9 feet, the elevation dying away in a westerly direction to nothing on the coast west of Wellington; while still further west, in the south island, the valley of the Wairau sank about 5 feet. East of the Rimutaka Mountains there was no elevation at all; consequently a fault must have been

formed, or increased, along the eastern base of the Rimutaka Mountains, and this fault was traced inland for about 90 miles. No subsidence followed this elevation.

But besides these sudden elevations and depressions, we have also evidence of slow gradual movements of the surface unaccompanied by earthquakes. The northern part of Sweden and the Baltic is gradually rising at the rate of from 6 to 2 feet per century, the more northerly portion moving the more rapidly, while the southern portion of Sweden is sinking, and many houses and streets are now below high-water mark. The west coast of Greenland is also known to be sinking. The Temple of Serapis, near Naples, shows by the lithodomus borings on the pillars that it must have sunk more than 25 feet since the Christian era, and afterwards been raised for a nearly equal amount, while observations have shown that until lately it has been again very slowly sinking. As these movements are not equable, it follows that it must be the land that is moving, and not the level of the sea.

Previous to the historical era, we have also evidence that the same kinds of movement took place. Along some coasts we find old beaches and sea-worn caves elevated above the present reach of the waves, while along others we see submerged forests. In coral islands and barrier reefs we have also sure evidence of long-continued slow subsidence.

Coral Islands. — The reef-building corals cannot exist in water that is more than 15 fathoms in depth; but in close proximity to coral islands, or *atolls*, and outside barrier reefs, the sea is often more than 2000 fathoms in depth. Consequently, the coral polyps could not have built up these reefs from the bottom of the sea.

The coral polyps begin to build in the shallow water

near the coast, forming what is called a *fringing reef* (*a* and *b* in Fig. 17, where A B represents the sea level).

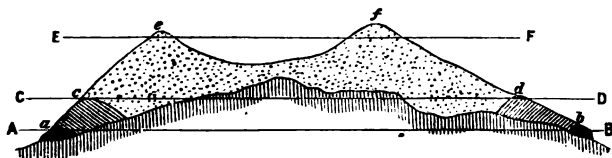


Fig. 17.

If the land is slowly sinking, they keep building up to the sea level, and as it is the habit of these animals to build more rapidly upwards than horizontally, it follows that as the land sinks, the coast recedes more and more from the reef, until at last a barrier reef is formed, marking the old coast line, but separated from the new coast line by deep water (*c* and *d* in Fig. 17, where C D now represents the sea level). Such is the barrier reef along the north-east coast of Australia. If, however, the first fringing reef was formed round an island, the barrier reef would form a ring round it, and when the top of the island at last sunk under the sea, the barrier reef would be converted into an atoll (*e f* in Fig. 17, where E F now represents the sea level).

While, therefore, coral islands prove extensive subsidence in comparatively modern times, we have, on the other hand, satisfactory proofs of just as extensive elevations; for tertiary rocks, containing marine fossils, are found at a height of 3000 and 4000 feet above the sea in California and New Zealand, while at the Niti Pass in Thibet they attain an altitude of 17,000 feet.

The rocks themselves also show plain evidence of having been moved. We have seen that the sedimentary rocks were originally deposited in nearly horizontal

positions, but we now find them inclined at all angles to the horizon, and even inverted. We often see beds of conglomerate standing quite vertical, a position in which it is evident the stones composing them could not possibly have remained before they were cemented together. Faults also necessarily imply that one portion of the rocks has been moved more than the other. We also sometimes find trees buried in the same spot in which they grew, and these are always at right angles to the plane of bedding, but often so far removed from the vertical that they could not possibly have grown in their present position.

It has consequently come to be regarded as a fundamental truth in geology that the land moves, while the sea remains stationary. By this it is not intended to imply that the level of the sea is always and absolutely constant, for it is evident that subsidence of land below the sea, as well as denudation and deposition, must raise, and elevation of land must lower its level; while subsidence of the ocean bed lowers, and elevation of the ocean bed raises its level. But as these different movements counteract each other, the result is that the level of the ocean remains practically constant. If all the land at present above the sea were washed down and deposited under it—the ocean bed remaining stationary—the level of the sea would not be raised more than 500 feet, probably.

The cause of these movements of the surface of the earth is not yet satisfactorily ascertained. Some geologists think that they are owing to the cooling, and consequent shrinking, of the interior, which makes the outer layers crumple and fold up; while others lay a greater stress on the inequalities caused in the temperature of the

outer layers by the removal of matter from one part of the globe and its deposition in another part. All, however, are agreed that they are in some way connected with the interior heat of the earth, and as the earth is gradually cooling, the exciting cause of movement must be gradually diminishing.

CHAPTER XIII.

PROOFS OF FORMER DENUDATION.

As the sedimentary rocks owe their origin to previous denudation, it follows that the formation of every new sedimentary deposit necessarily implies that there has been somewhere else an equal amount of matter denuded or washed away. When, therefore, we find whole mountain masses made up of sedimentary rocks, we ought to expect to find proofs that whole mountain masses have also been entirely removed by denudation; and such is the case. Professor Ramsay has shown that the missing beds removed from the summit of the Mendip Hills in England must have been nearly a mile in thickness, and he has pointed out considerable areas in Wales where a series of strata not less than 11,000 feet in thickness has been swept off. Indeed the marks of denudation are universal, for it is entirely owing to its action that we find beds cropping out to the surface. Where the beds are horizontal, and the same bed crops out on either side of a valley, it is evident that the bed was once continuous,

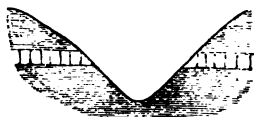


Fig. 18.

and that the portion which once occupied the valley has been removed. When the strata are inclined, it is also equally evident that the whole of their edges have been washed away (see Fig. 5). When the strata are thrown into folds, the effects of denudation are still more apparent (see Figs. 6, 7, and 12), whole tops of curves having been removed, leaving the beds cropping out to the surface on either side of the anticlinal axis.

Sometimes we find level tracts of country underlain by folded and contorted rocks (Fig. 8); in this case also it is quite evident that the whole of the upper surface must have been planed down by denudation.

When part of a bed has been removed, leaving one or more patches isolated from the main mass of the rock



Fig. 19.

(Fig. 19), these patches are called *outliers*. Outliers are therefore in themselves proofs of denudation.

Faults also prove that one set of rocks have been elevated, or, have subsided more than another set in close proximity, and yet it is rare to find this difference in elevation showing at the surface, both sides of the fault having been almost always reduced to a uniform level by denudation (Fig. 15). Unconformity among rocks proves successive denudations; for there is, first, the denudation which exposed the edges of the lower set of beds upon which the upper set rest (Figs. 9 and 10, *a b*); and secondly, the denudation that exposed the edges of the second set, and allowed the unconformity to be seen.

CHAPTER XIV.

EARTHQUAKES.

EARTHQUAKES are defined by Mr R. Mallet as waves of elastic compression traversing the substance of the earth. They are probably caused by the fracture or sudden movement of rocks below the surface, joints or faults being formed.

When a blow is suddenly applied, or when a previously steady or increasing pressure is suddenly relieved, a pulse or wave of force is transmitted in all directions from the centre of impulse. The waves travel outwards in spheroidal shells from the centre of impulse, and emerge from the surface at various angles. Those immediately over the centre of impulse will be vertical, and as they recede from this they will more and more approach a horizontal direction. The vertical line from the *centre*

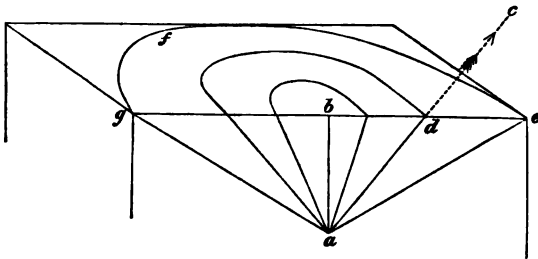


Fig. 20.

of impulse (Fig. 20, *a*) to the surface is called the *seismic vertical* (*a b*), and the angle that the wave makes with

the horizon when it emerges from the surface is called the *angle of emergence* (*c d e*). The shock first reaches the surface at the seismic vertical, and spreads from thence in concentric circles, called *coseimal lines* (*e f g*), along which the shock reaches the surface at the same moment. The *velocity of transit* is the rate at which the wave is propagated through the earth from particle to particle. This is often very different from the rate at which it appears to travel along the surface, which depends upon the depth of the centre of impulse. The *velocity of shock* is the velocity of each particle as it moves from and back again into its place. It is always much less than the velocity of transit.

If a row of billiard-balls are placed in a line touching one another, and another ball is made to roll gently up and strike the nearest of those in the line, a wave of elastic compression will be transmitted through the line of balls, and the last of the line will move off. The time between striking the nearest and the movement of the last ball will be, if reduced to feet per second, the velocity of transit ; while the velocity of the rolling ball will, if reduced to feet per second, represent the velocity of shock. It is the velocity of shock and not the velocity of transit that does the damage to buildings during an earthquake.

The velocity of transit varies with the nature of the different materials it has to traverse. From experiment Mr R. Mallet found that the shock of exploded gun-powder traversed ordinary granite at the rate of 1665 feet per second ; shattered granite at 1306 feet per second ; slate at the rate of 1089 feet per second ; and wet sand at the rate of 825 feet per second. The causes of retardation are the discontinuity of the rocks, the less amount

of elasticity of the material, and the less amount of original compression causing the shock.

If two rows of bricks are set up on end, those in one row being only one inch apart, while those composing the other are six inches apart, and the first bricks in each row are pushed over at the same moment and with equal velocities, it will be seen that the wave of transit, as it may be called, travels much faster along the row in which the bricks are only one inch apart than in the one where they are six inches apart, each brick having farther to move in the last case before it strikes its neighbour. If now the bricks are again set up in two rows at equal distances in each row, and the first bricks in each row are pushed over at the same moment, but with different velocities, it will be seen that the wave of transit travels faster along that row the first brick of which was pushed with the greater velocity, because in this row each brick knocks over its neighbour sooner than in the other.

The *amplitude* of the earth wave is half the amount of the actual motion of the particles, or the greatest distance a particle is removed from its original position.

If the direction and amount of the angle of emergence at two or more places is known, the position of the centre of impulse can be calculated with more or less certainty; and if the position of the centre of impulse and the time of arrival of the shock at two or more places be known, the velocity of transit can then be calculated more or less accurately. Instruments for ascertaining the direction and amount of the angles of emergence of earthquake waves are called *seismometers*; they depend upon the principle that *vis inertia* will keep mercury stationary for a short time while the glass tube containing it is moved by the earthquake wave, so that an index may re-

cord how much and in what direction the glass tube was moved while the mercury remained stationary. The time of arrival is taken by a clock so arranged that the earthquake stops it, while the velocity of shock is calculated from the proportions of the broadest cylinder, out of a series set up on end, which the earthquake was capable of overturning.* Objects are always overthrown in the line of the wave path, while fractures take place transverse to it, and an examination of these may give roughly the angle of emergence. The velocity of shock and the amplitude of the wave can also be estimated from the damage done to buildings.

In the above remarks it has been supposed, for the sake of simplicity, that the centre of impulse was very small, and that the rocks surrounding it were homogeneous, but in nature this is never the case. The centre of impulse is generally a narrow fissure, with considerable length and breadth, and the rocks vary considerably in character. Now as the earth wave must leave the centre of impulse in all directions at right angles to its surface, it follows that the impulse will be most effective in the directions perpendicular to the general plane of the fissure, and the outward progress of the wave will therefore be in ellipsoidal shells whose major axis is perpendicular to the plane of the fissure. If the fissure is vertical, the

* The velocity of shock necessary to overturn a solid right cylinder whose height is a , and diameter is δ , can be found by the following formula given by Mr Mallet.

$$v^2 = \frac{15 \delta^2 + 16 a^2}{12 a^2} \times g \sqrt{a^2 + \delta^2} (1 - \cos. \phi).$$

Where ϕ is the angle formed by the line joining the centre of gravity and the edge of the base with the side of the cylinder.



coseimal lines will be ellipsoids round the seismic vertical as a centre ; but if the fissure is inclined, the major axis of the ellipsoid will be inclined also, and the coseimal lines will form ovals, the seismic vertical being situated towards the narrower end (Fig. 21, *a b*).

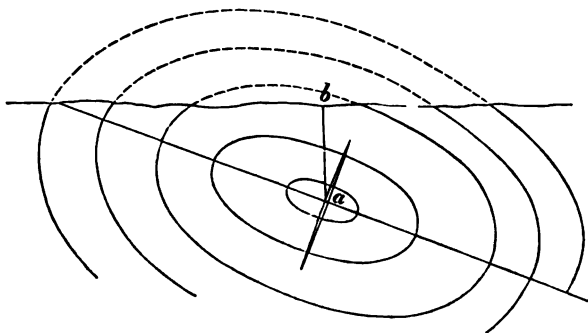


Fig. 21.

The coseimal lines and the directions of the earth wave are also complicated by the differences in the elasticity and compressibility of the surrounding rocks, the earth wave being refracted in passing from one rock to another, and sometimes even partly reflected back, so that the forms the waves assume on the surface is generally more or less ellipsoidal, but rapidly becoming very complex.

The progress of the earth wave is also much influenced by the configuration of the surface as well as by the structure below it. Among sedimentary rocks the wave travels most easily and rapidly along the strike of the beds, as they are more continuous in this direction than in any other, consequently it is often transmitted more readily in the direction of mountain chains than across them. Loose incoherent beds of gravel or sand soon

deadened the shock if the angle of emergence is low ; while a large deep continuous valley will entirely extinguish the wave, and if the angle of emergence is low, so that the portion of the wave passing below the valley does not reach the surface for a considerable distance beyond the

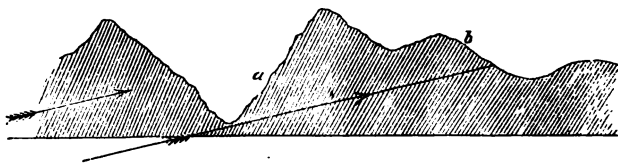


Fig. 22.

valley, a large area (Fig. 22, *a b*) will be left on that side of the valley away from the centre of impulse, which will experience no earthquake at all.

Mr R. Mallet calculated that the mean depth of the centre of impulse of the Calabrian earthquake of 1857 was 5·3 miles, but that it was 9 miles long and 3 miles deep. The velocity of transit was about 800 feet per second ; the velocity of shock 12 feet per second ; and the amplitude of the earth wave 3 or 4 inches. This was a very severe earthquake.

The wave of shock is generally accompanied by a wave of sound, which is often heard before the shock is felt. This is owing to sound travelling quicker through the air from the seismic vertical to the observer than the velocity of transit of the earthquake shock.

Earthquake Waves.—When an earthquake takes place under the bed of the ocean, a large body of water is suddenly lifted and dropped again. This causes a wave called an earthquake wave, that is propagated outwards in rings, and often rushes over the land, doing immense damage. The velocity of this wave depends

upon the depth of the ocean, the velocity increasing with the depth. The earthquake wave that traversed the North Pacific from Japan to California in December 1854 had a velocity of 6.1 miles per minute; the velocity of the wave that crossed the South Pacific from Peru to New Zealand in August 1868 was about 5.9 miles per minute. The wave raised during the earthquake at Lisbon in 1755 travelled to the Barbadoes at the rate of 7.8 miles per minute, while it went to London at very little more than 2 miles a minute. In the open sea the height of these waves is inconsiderable; but when the water shoals near a coast, the immense volume and velocity of the wave force it up to a great height.

Secondary Effects of Earthquakes.—When an earthquake shock traverses solid rock equally supported on each side, no fissure or crack can be formed, because the velocity of transit is so much greater than the velocity of shock that the whole mass moves together. For this reason the earthquakes of South America cause no damage to the mines. But when a mass of rock is unsupported on one side, and the cohesion between its particles is not very great, fissures are formed more or less at right angles to the direction of the earth wave, if the force of the impulse is sufficient to overcome the cohesion of the particles. This is why alluvial plains cut through by deep river beds suffer more than mountains. It is on exactly the same principle that when the first of a row of billiard-balls is struck the last of the row flies off, while the intermediate ones retain their places.

Distribution of Earthquakes.—All large earthquakes are followed, and are often preceded, by several minor shocks. It has been estimated that on an average more than sixty earthquakes of considerable magnitude

take place every year. They are most common in volcanic districts, but are also known in many mountain chains, and near the mouths of large rivers, such as the Ganges, Indus, and Mississippi. Those in paroxysmal volcanic districts are usually quite local, as are also those in mountain ranges; but those in the neighbourhood of massive volcanic districts are often very extensive. The earthquake in Peru in August 1868 extended for 2000 miles along the coast; and it is most probable that the greater is the extent of an earthquake, the deeper situated is the centre of impulse.

CHAPTER XV.

PALÆONTOLOGY.

PALÆONTOLOGY, or the study of fossils, forms a separate department of geology, and is properly a branch of the biological sciences, for an accurate knowledge of living plants and animals is necessary in order to study successfully the more obscure remains found entombed in the rocks. Still there are some parts of palæontology which belong properly to geology, such as the changes that fossils have undergone since they were embedded; and it is always necessary that the geologist should be able to appreciate and make use of the facts and deductions supplied him by the palæontologist, for without this knowledge he would be deprived of his most trustworthy and serviceable weapon. By a *fossil* is meant any mark in a rock which indicates by its form the former existence of life. Thus not only are shells, bones,

&c., fossils, but the marks left by shells, or the footprints of animals, are equally considered as fossils. No strong line divides fossil from recent plants and animals; but the former may generally be distinguished as having been buried by natural causes.

The organic remains most frequently found in rocks are the harder parts of animals and plants. The soft parts are almost always absent; and while the valves of shells, and more especially bones, are generally detached, the delicate spines and markings that characterised the living animal are often perfectly preserved. This shows that the process of burial was sufficiently slow to allow of the soft parts decomposing before they were covered up, while the preservation of striæ and spines proves that the animals died in still water. Exceptions, however, occur, for the soft parts of cephalopods and the delicate wings of butterflies have occasionally been found; while, on the other hand, it is not uncommon to find shells and bones rolled, or rubbed, and broken.

Many fossils have also been much broken or distorted by the pressure of the rocks subsequently to their having been embedded, and this is more especially the case with sea-urchins (*Echinidæ*) and lamp-shells (*Brachiopoda*), into the interior of which it is difficult for the sand or clay to find its way.

Fossils occur principally in marine sedimentary rocks, consequently the majority of them are animals that inhabited the sea, and as the shells of the marine mollusca are the most abundant, they are to the geologist the most important of fossils. Not only do molluscan remains, by their abundance, enable him to compare together and correlate distant formations, but they also afford him the surest evidence of the marine, estuarine, or lacustrine

origin of a deposit, and of the depth and temperature of the water under which it was formed.

When a fossil is buried in a rock, the first change that takes place in it is generally the loss of all colour, followed by the abstraction of its gelatine, thus rendering it light and friable. If the rock is not very pervious to water, as clay, the changes often stop here ; but if water gains access to a shell buried in a rock, such as sandstone, deficient in carbonate of lime, the whole of the calcareous matter is generally removed, and an *impression* of the exterior, enclosing a *cast* of the interior of the shell, is all that remains. Sometimes a further change takes place ; as the calcareous matter is removed, it is replaced by silica, or more rarely by iron pyrites, and the shell is then mineralised or petrified.

From this cause fossils are rare in sandstone, and occur chiefly as casts, while in limestones and clay they are much more abundant. Concretionary action tends to preserve fossils, so that the ferruginous nodules in sandstones and the calcareous concretions in clays or argillaceous sandstones often contain fossils when the rest of the rock is quite barren. It is also necessary, in order that fossils may have a chance of being preserved, that the deposit in which they are buried should be undergoing depression, so that they may be thickly covered up, and the rock consolidated by the pressure. When fossils are buried in a rising deposit, which cannot get consolidated, they disappear in a comparatively short time after being elevated above the sea ; and it is owing to this cause that fossils are generally extremely rare in raised marine gravel and silt beds.

A careful examination of the fossils found in different rocks has shown that species have come into existence

at different periods, and that after having inhabited the earth for a longer or shorter time, they have gradually died out, and have been replaced by other species; so that rocks of different ages contain different kinds of fossils.

The older fossils differ more from living forms than do those found in the younger rocks; indeed, these contain as fossils many of the animals and plants now inhabiting the earth. These fossil remains of living species get gradually more and more numerous, in comparison with the extinct species found with them, the nearer we approach to the present time, until in the very newest raised beaches we find nothing but recent species contained in them.

Whenever we can prove by stratigraphical evidence, such as unconformity, that a considerable time elapsed between the deposition of two sets of strata, we also always find a considerable difference, or total dissimilarity, between the fossils occurring in each set of beds. Sometimes we find a considerable difference between the fossils of two beds which apparently follow one another in close sequence; and when this difference in the fossils cannot be accounted for by a change in the "station," such as a change from mud to sand, we infer that the division between the two beds marks a long interval of time, which is not represented by any rocks in the district, and that during that time the species gradually changed from those found in the lower to those found in the upper bed. This is called a *break in the succession of organic remains*, or a *break in the geological sequence*, according to the point of view from which we are dealing with the subject.

Imperfection of the Geological Record.—

When we consider how very small a percentage of the animals and plants that die are covered up before they are completely destroyed, how many after they are covered up are removed by the percolation of water or obliterated by the action of heat, what an enormous portion of the sedimentary rocks have been removed by denudation, what a very small part of the fossiliferous strata are available for our examination, and of that small part that only portions here and there have as yet been explored, it is evident that our knowledge of the extinct faunas and floras of the earth is fragmentary in the extreme, and consequently we must be very cautious in drawing conclusions based on negative evidence. Notwithstanding this, we have sufficient positive palæontological evidence to show that species had always, as now, a distinct geographical distribution, but were more widely spread during the older periods ; that the number of species and genera has increased with the age of the earth ; that species changed more rapidly in later than they did in earlier times ; and that, on the whole, the series of succession has been on an ascending biological scale.

CHAPTER XVI.

CHRONOLOGICAL CLASSIFICATION OF ROCKS.

As rocks are of different ages, it is possible to classify them chronologically as well as by their original composition ; and although the geologist has no means of ascertaining the actual age of any particular rock, he has many aids in investigating their relative ages.

The relative ages of the various sedimentary rocks can be made out more readily and with more certainty than those of the eruptive rocks, consequently the former are taken as the foundation of a chronological scale to which the latter are referred.

Sedimentary Rocks.—The best and most important test, when it can be applied, of the relative age of sedimentary rocks, is the superposition of one on another; for it is evident from their mode of origin that the upper bed must be younger than the one upon which it rests. But although this is necessarily true for those parts of the beds which rest immediately on one another, it is not always absolutely correct when one part of a bed is compared with a distant part of another bed. For example, a bed of sand may be forming along a coast line; outside of this a bed of clay may be in process of deposition; while further out still a stratum of limestone or chalk may be accumulating. If now the land is slowly sinking, the shore line will recede, and the inner edge of all these formations will follow it; so that the old sand-bed will be covered by clay, and the clay by limestone or chalk.

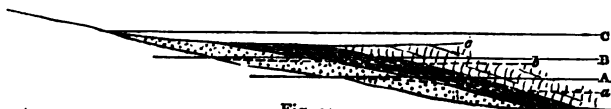


Fig. 23.

So that in time we should have a stratum of sandstone covered by clay or shale, which would be again overlaid by limestone; and yet different parts of all these three beds were formed contemporaneously. This is shown in Fig. 23, where A, B, and C represent the sea level at three successive intervals, and *a*, *b*, and *c* the sea bottom at each interval with the deposits forming on it.

Another very satisfactory kind of evidence of the relative ages of two rocks is when fragments of one are found included in the other. Unfortunately this kind of evidence is not sufficiently common to be of very great importance.

The mineral composition of a rock is of the greatest use in connecting beds at short distances from each other, as on opposite sides of a valley; but as the composition of a rock often varies considerably in a horizontal direction, this test cannot be depended upon except for short distances; and as rocks of different ages often have a similar composition and appearance, mistakes are apt to arise if too much trust is placed in it alone. If, however, instead of a single bed a whole set of beds are found repeated in the same sequence at distant localities, the evidence then is sufficiently strong to connect them as parts of the same formation.

But by far the most useful evidence that rocks in distant localities are of equal age, or *equivalents*, is found in the fossils contained in them. It has been already mentioned that rocks of different ages contain different fossils, and the converse is also true, viz., that rocks of the same age contain the same fossils, provided that we view them on a sufficiently large scale.

It has been ascertained that each great group of rocks has an assemblage of fossils peculiar to it, although some also range higher or lower into the beds above or below it. Those fossils which are widely spread in a group of rocks, but do not occur above or below it, are called its *characteristic fossils*; and all rocks containing these fossils are considered as equivalents, or belonging to the same period; or, as it is sometimes called, belonging to the same *geological horizon*.

A great difficulty, however, meets us when classifying rocks by their organic remains. Biologists have shown that each species originated in one particular district of the earth, called its *specific centre*, and that from this they have migrated outwards as far as they were able to do. Consequently the time at which any species commenced its existence at its specific centre is rather earlier than when it commenced to inhabit the surrounding districts; and the further from the centre, the later may be the time of its first appearance in that district. The species also may become extinct near its specific centre, while it still continues to live in the surrounding districts. Identity of fossil species may therefore mean a difference in time if viewed on a small scale.

This difficulty, however, only arises when we compare very distant formations, and it can only be overcome when we have traced out the migrations of the different species. It is therefore necessary that a separate chronological classification should be first made out for each large area, and that they should then be compared with adjoining areas before we can form one for the whole earth.

It will be long before this can be accomplished. Meanwhile we refer provisionally the formations of each area as well as we can to the standard scale that has been drawn up for the rocks of Europe; but these identifications are only supposed to be approximate, and in order to imply that a strict contemporaneity, or synchronism, is not to be understood when comparing rocks in distant areas, geologists say that the chronological arrangement of the rocks of any particular area are *homotaxial* with the standard.

The following table exhibits the standard which has been drawn up from the European rocks:—

CAINOZOIC	{	Pleistocene Period.
OR		Pliocene Period.
TERTIARY ERA.		Miocene Period.
		Eocene Period.
MESOZOIC	{	Cretaceous Period.
OR		Jurassic Period.
SECONDARY ERA.		Triassic Period.
PALÆOZOIC	{	Permian Period.
OR		Carboniferous Period.
PRIMARY ERA.		Devonian Period.
		Upper Silurian Period.
		Lower Silurian Period.
		Cambrian Period.
		Laurentian Period.

The terms *Formation* or *System*, *Group*, *Series*, and the names of particular rocks refer only to the restricted geographical areas through which the beds forming them can be traced. Thus we have the Wealden formation and the Headon series of England, the Clinton group of North America; also the Wenlock limestone, the Chazy limestone, the Bath oolite, the Chalk, the London Clay, &c. &c., all of which latter refer to particular deposits only.

Epoch means a period of time, and is universal; formation, group, and series mean particular sets of beds only, and are local. Thus we can speak of the epoch during which the Niagara group was being formed. An epoch comprises a number of nearly equivalent or homotaxial groups or formations. In this respect it is similar to the term *Period*, but it implies a less interval of time. The epoch of the Niagara group, for instance, is only a portion of the Upper Silurian period.

Much confusion, however, exists in this part of geological nomenclature, owing to the fact that the names of

the formations of Europe have also been used as the names of the periods during which they were formed.

Formations are now generally named from the localities where they are best exhibited, or where organic remains are most abundant; but in the earlier days of geology names were often given from some local peculiarity of mineral composition or of texture, such, for instance, as Greensand, Old Red Sandstone, and Oolite. It is from this that the names Cretaceous and Carboniferous periods have got into our standard scale; and it may be as well to remind the student that these names imply time only, and have nothing to do with the nature of the rocks forming them. Coal, for instance, may be of any age, while it may be entirely absent from rocks in a certain district belonging to the Carboniferous period.

Neither must it be supposed that the various periods of the standard scale represent equal portions of time. The divisions are based chiefly on changes in the organic remains, and it is certain that the older periods represent far more time than the newer, for they are much thicker. The following table of the relative thickness, the number of times the animals have changed, and the proportional rapidity of change for each of the three large eras will show this:—

	PALEOZOIC.	MESOZOIC.	CAINOZOIC.
Proportional thickness of } deposits, . . . }	9½	2	1
Number of changes in fauna,	5	3	3
Proportional rate of change,	1	3	6

If, therefore, species changed six times as fast during the Cainozoic era as they did during the Palæozoic era, we can correlate the newer formations with six times the accuracy that we can the older ones ; and it is probable that the slower rate of change during Palæozoic times, by giving greater time for migration, will account for the more universal dispersion of the Palæozoic animals.

Eruptive Rocks.—When a chronological classification is made out for the sedimentary rocks of a district, the eruptive rocks can be referred to it with more or less accuracy by observing which rocks are pierced or altered by them, and which have been deposited after the eruptive rocks had undergone denudation. The first gives us a maximum, the latter a minimum, value for their age. Included fragments of other rocks can occasionally be recognised ; while in the case of tuffs, agglomerates, and contemporaneous sheets, interstratification, and sometimes even organic remains, make the determination of their age as satisfactory as is that of the sedimentary rocks.

The age of crystalline schists is twofold. First, we have to find the period of their deposition, which is their true age, and which can only be ascertained by superposition ; and secondly, we have the time when they were metamorphosed. To find out this, we can examine how far up in the scale the metamorphism has extended, which gives us a maximum, and a minimum may sometimes be obtained by the age of unmetamorphosed strata deposited upon the denuded edges of the schists.

Crystalline schists are known of all ages from the Laurentian gneiss of Canada to the Eocene mica-schists of the Alps, and at the latter place they are associated with granite of a similar age.

CHAPTER XVII.

PHYSIOGRAPHY.

By physiography, or surface-geology, is meant the study of the origin of the minor features of the surface of the earth, such as mountains, valleys, plains, &c.

Mountains.—Mountain chains are of two kinds, the one formed by folded and contorted rocks associated with crystalline schists and granite, the other formed by more or less horizontal rocks associated with the products of massive volcanic eruptions. The Alps are a type of the first kind, the Andes of the second kind. Paroxysmal volcanic eruptions form isolated mountains only, and not mountain chains.

But to whichever class the mountain chain may belong, the external form of each individual mountain is but very little influenced by its internal structure. A close examination shows us that the whole of the upper parts of the rocks have been broken off and removed by denudation, while the fact of the whole watershed being covered by a labyrinth of small valleys, each of which slopes gradually into the main valley, is a convincing proof that they are all owing to the equable action of running water, and not to the irregular movements of elevation and subsidence.

Thus, while the main mass of the mountain range is due either to elevation or to eruptive action, the valleys intersecting the mountains have been formed by erosion.

Valleys.—Now these valleys could not have been excavated by the sea beating against a coast line, for the

sea cannot cut out valleys, unless the whole of the part cut out is much softer than the coast line, for the force of the waves, and consequently the wear of the rocks, is much greater on the coast than up a sheltered valley. But valleys in mountains are not hollowed out exclusively in soft rocks, but cross all of them indiscriminately. Neither could the valleys have been worn out by marine currents, for marine currents could not form a sloping valley running up to the highest land without any outlet, neither could they possibly form any of the tributary valleys. We also know from soundings that there are no small valleys, like the valleys among mountains, under the sea, but only slight and gently sloping undulations.

It is therefore to the rivers running in the valleys, and to the streams of rain-water running down the sides of the hills into the rivers, that we must look for the cause of the erosion that has excavated the valleys. That the latter is a very influential agent is evident when we remember that the rivers themselves can only cut downwards, and that the cliffs thus formed might decompose and fall down until the slopes had attained an angle of about 38° , but that after that the decomposed rock could only be carried into the river bed by running water; and we are not without direct evidence of this *pluvial action*. In many parts of Switzerland, and notably in the Tyrol near Botzen, valley-terraces are seen cut into columns of indurated mud from 20 to 100 feet high, each being usually capped by a single stone, which has defended that portion immediately below it from the rain which has washed away all the deposit around, and thus left the pillars.

If, therefore, all valleys have been formed by rivers, it follows that those submarine valleys called *fjords* are old

river valleys depressed below the sea-level. The student must always remember that the surface features of the earth, as we now see them, are not owing to one continuous, unvarying cause, which is still in action, but are the result of many changes in level and climate.

Valleys widen as they descend, owing to the lower parts having been longer exposed to lateral denudation by rain than the upper parts. Exceptions, however, occur when the rocks are of different hardness—those near the mouth of the valley resisting decomposition or denudation better than those higher up. In this way occasionally a ridge of hard rock is left standing out above the general features of the country, forming a chain of hills which runs at right angles to the courses of the rivers which cross it. A good example of this is seen in the South Downs of England, where the rivers rising in the Weald cross through the chalk hills to fall into the English Channel.

Valleys are gradually cut back into the mountains, and when two, situated on either side of a ridge, meet, a *pass* is formed.

When a mountain range is depressed so far below the sea-level that only the higher parts of the ridges are above the water, the strong tidal currents that flow through the passes between the peaks prevent deposits being formed in them; and when the land again rises above the sea, they often form the channels through which the new rivers now run, the old valley having been filled by newer deposits. As the land continues to rise, the river cuts its way down through the old pass, while the soft newer deposits that partly fill up the old valley are readily removed nearly to the same level; and the phenomenon is seen of a river suddenly leaving its

old valley and cutting at right angles across the mountain range which formerly bounded it. Many good examples of this are seen in British Columbia and New Zealand.

Lakes.—Salt-water lakes, which have no outlet, are no doubt due to original inequalities in level when the land rose above the surface of the sea, these inequalities being caused either by subsidence or by an absence of deposition on those particular areas.

Fresh-water lakes are sometimes formed in volcanic countries by a local subsidence, or by a lava stream flowing across a valley. Sometimes they are caused by the sea throwing up a sand-bank across the mouth of a river, or by a river during floods throwing up a bank across a tributary valley; but these are more of the nature of lagoons than lakes, and the majority of true lakes lying in river valleys have been formed by the action of glaciers.

In almost all cases the valley above the lake is larger than the lake bed, consequently the lake must have been formed after the valley, or it would have been filled up. But as the streams now running into every lake are slowly but surely filling it, a lake can only be considered as a transitory condition of a river.

Some lakes in a mountain district may be caused by the terminal moraines of old glaciers damming up the valley; but this cannot often be the case, for the stream from a glacier generally cuts the terminal moraine nearly down to its base, and by far the greater number of lakes lie in *rock basins*—that is to say, in hollows surrounded on all sides by solid rock. These rock basins are sometimes 1000 or 2000 feet deep, and several of the lakes in Northern Italy and New Zealand have been excavated considerably below the present sea-level.

The débris brought down by a glacier to form the terminal moraine covers up that portion of the valley, and marks a point of no erosion. Below the moraine the river gradually deepens its channel, while above the moraine the erosion of the glacier gradually decreases the slope of the valley. The erosion of a glacier depends principally upon the thickness of the ice and the rapidity of its motion; and as they always get thinner and move slower near their terminations, the erosion is less there than it is higher up the valley. If the valley is flat, a rock basin will be the result; if it be steep, the glacier has a large amount of work to do before the slope of the valley can be reversed; and if the glacier retreats up into the mountains, or altogether disappears, before this is done, no rock basin will be left behind, and consequently no lake will be formed. This is the reason why lakes are so numerous in a flat country like Canada, that has been formerly covered by an ice sheet, while they are often wanting in mountain valleys that were once filled by glaciers.

Plains are of two kinds. One, called *plains of deposition*, are merely the level surface of a marine or lacustrine deposit which has never been disturbed nor much eaten away by denudation, the strata always lying in a horizontal position. The other, called *plains of denudation*, are where disturbed or inclined strata have been



Fig. 24.

denuded down to a level surface. Plains of denudation must have been formed by the sea, for the sea is the only

known agent that can cut a level surface. They are not truly level, but slope seaward. We can often trace the old plain of marine denudation in a hilly or even in a mountainous country, the hills or mountains all rising to one plain (Fig. 24, *a b*), which has a gentle slope seaward. It is owing to this rise in the old plain of denudation that the central mountains of a chain are the highest.

River Deposits.—The action of rivers in forming or removing deposits in their valleys is exceedingly complex, but it depends entirely on one principle, viz., the varying velocity of the moving water. It has been ascertained that the power of a river to move bodies varies as the sixth power of its velocity, so that a small difference in the velocity makes a very great difference in the size of the stones it is able to move.

The velocity of a river depends upon the amount of rainfall; on the shape of the valley, whether it be broad or narrow, or whether it alternately expands and contracts; on the slope of the valley; and on the obstructions caused by rocks and vegetation in its course.

Floods bring down material which fills up the bottom of the valley, and which, if the average velocity of the river is decreasing, cannot be removed. Each flood brings down smaller material, and the valley is gradually filled up. If, on the contrary, the average velocity is increasing, the material formerly brought down by floods is removed by the river, and a deep channel is formed.

The slope of a valley as well as the rainfall over the catchment basin, and consequently the velocity of the river, are increased by elevation and decreased by subsidence. Rivers, therefore, deepen their beds during elevation, and fill them up during subsidence. But owing

to obstacles in the river bed turning the direction of the stream, a river is constantly changing its course, and swaying from side to side in its valley ; and if a river is cutting down through the alluvium that it formerly deposited during a period of subsidence, flat-topped *terraces*, rising like steps one above the other, are left on either side. River terraces are therefore, like raised beaches, proofs of elevation.

But while the sea-level prevents the further deepening of a valley in its lower part, the erosion still goes on in the upper portions where the slope is steep, and the material thus brought down is deposited at or near the mouth, according to the velocity of the river. If the mouth is protected by being in a sheltered bay, the deposits gradually accumulate, and a delta is formed ; but if the mouth of the river is swept by a marine current, the fine material is removed, and the current forms a sandbar across the mouth of the river.

CHAPTER XVIII.

MINERAL VEINS.

Concretions are more or less spherical, or irregularly-shaped, nodules found in rocks, and have been formed by the segregation of mineral matter towards particular points. They are most abundant in clays and earthy limestones, but an imperfect concretionary structure is sometimes seen in sandstones as well as in the crystalline schists and eruptive rocks. They often, but not always, contain a fossil as a nucleus. They vary in size

from that of a pin's head to twelve or more feet in diameter.

In clays and sandy clays the concretions are usually calcareous or ferruginous. The larger calcareous ones often have cavities in the centre, from which numerous cracks radiate towards the surface, all of which have been filled up with carbonate of lime. These are called *septaria*, while the ferruginous concretions form *clay iron-stone*, a valuable ore of iron. Iron pyrites also often forms concretions in clay.

In sandstones the concretions are generally small, and are always ferruginous. In some places concretions of phosphate of lime are found, which were formerly thought to be of coprolitic origin, *i.e.*, fossil excrement, but they have been proved to be concretions round sponges.

In limestones the concretions are generally siliceous, which when pure are called *flint*, and when impure *chert*. The oolitic structure of some limestones is also of concretionary origin; the globules are larger in proportion as the rock is softer, a rule which very generally holds good with all concretions.

Mineral Veins.—A mineral vein is a more or less tabular local accumulation of minerals in a rock. For the sake of convenience, veins may be divided into metalliferous and non-metalliferous, according as they do or do not contain metals.

Non-metalliferous veins are found in all kinds of rocks. The minerals always occur in a more or less crystalline state in cavities or in veins or strings traversing the rock. They are rarely straight for more than a few yards, and seldom extend for any great distance. Their contents depend chiefly on the rock they traverse; in limestones they are filled with calcite, in siliceous rocks with quartz.

There can be no doubt but that they have been formed by infiltration from the surrounding rocks into cracks which have been caused by shrinkage. These veins differ from concretions only in the minerals having been deposited in open cracks instead of in the body of the rock itself.

Metalliferous Veins.—These are not so universally distributed as the last, but are confined to indurated, metamorphosed, and fractured rocks, which are also generally but not always pierced by eruptive rocks. As a consequence of these characteristics, a mining district is commonly a mountainous one.

These phenomena are all produced by the action of heat more or less intense, and more or less long continued; and mining districts may be divided into two classes as follows, according as the heat acted on the rocks at a great depth or near the surface:—

- (a.) Districts composed of metamorphosed rocks, including slates, generally belonging to the older periods.
- (b.) Districts composed of volcanic rocks, often of very recent age.

While all kinds of metals are found in districts of the first class, those of the second contain only copper, zinc, lead, arsenic, mercury, silver, and gold.

Kinds of Veins. — *Reefs, lodes, or rake veins* are extensive fissures crossing all the rocks of a series. They often extend for many miles in length and to an unknown depth. They are usually not far removed from the perpendicular.

Pipe veins are irregular cavities in rocks, inclined at various angles to the horizon. They may or may not be connected with a fissure.

Flat veins are flat, more or less tabular ; veins which lie in the plane of bedding.

Gash veins are wedge-shaped veins which die out downwards.

Contents of Veins.—The contents of veins are divided into the *vein-stone* or *gangue*, which is the sparry or crystalline masses of the earthy minerals, such as quartz, calcite, fluor-spar, &c.; and the *ore*, which includes all compounds of the metals proper with oxygen, sulphur, carbonic acid, &c. The surrounding rock is called the *bed-rock* or *country*.

Veins generally have distinct walls. The upper, when the vein is inclined, is called the *hanging wall*; the lower the *foot wall*. Sometimes, however, no distinct walls can be made out.

Veins sometimes contain water-worn stones, which can only have been produced by underground streams. More often they contain angular fragments of the bed-rock, and this is particularly common in slaty or schistose rocks.

Sometimes large detached masses of the bed-rock, called *riders*, are found ; they are always more or less parallel with the walls of the vein. Sometimes fragments of the gangue of one-half the vein are found forming a breccia in the other half.

The contents are often arranged in layers of different materials parallel to the walls, and these are sometimes divided by clayey bands called *flucans*. In most veins the rock forming the walls is decomposed into a clay similar to the flucans, which is called the casing.

Direction of Veins.—With unimportant exceptions, veins may be said to lie in divisional planes of the rocks they traverse, whether it be planes of bedding

or of jointing ; consequently they generally take definite directions in each district ; but these directions are different in different districts.

Origin of Veins.—Some suppose that veins have been open joints filled up with mineral matter ; but it is impossible to conceive any large inclined fissure or cavity remaining open for so long a time as would be necessary to fill it, for we know that one of the great difficulties of the miner is to keep the vein open while he is extracting the ore. The occurrence of riders is also quite unexplained by this theory. Others suppose that veins are the result of replacement, which gradually removed the rock and replaced it with other minerals. This theory originated with Zimmerman * in 1749 ; but it is not in this way easy to account for the parallel layers in veins, nor for the well-formed crystals, nor for the defined walls, nor for their lying in divisional planes of the rocks.

All difficulties seem to be removed if we suppose veins to have originated in narrow fissures, which have been from time to time gradually enlarged, the walls sometimes splitting in a new place and leaving attached to the vein a mass of rock, which will now become a rider. It is often found that the walls of a vein are fissured so as to break parallel to the vein. The occasional disappearance of the walls can be explained, as was taught by Werner, either by replacement or by the decomposition of the walls by the water in the veins.

Filling of Veins.—The following are the four most important theories that have been brought forward to account for the filling of veins :—

(a.) *Injection in a Molten State.*—Proposed by Dr

* Obersächsische Bergakademie.

Hutton in his "Theory of the Earth," 1788. This theory requires that the veins should have been open fissures, and it would not account for pipe and gash veins, which have no continuation downwards. The specific gravity of all vein quartz is also 2.5 to 2.6, which is the same as that of quartz formed in the wet way; while the specific gravity of quartz formed in the dry way, or by igneous fusion, is 2.1 to 2.3.

(b.) *Sublimation from Below*.—First proposed by J. Becher in his "Physica Subterranea," 1669. The same objections to the last theory apply also to this. It is also certain that the vein-stone or gangue has had the same origin as the ore, and it is difficult to conceive how quartz and carbonate of lime could be sublimed without the whole of the rocks melting on each side.

(c.) *Deposition by Thermal Springs*.—First proposed by Elie de Beaumont, "Bulletin IV." The arguments against this theory are, that it will not account for veins that die out below, nor for the occurrence of ore in the casing or in the bed-rock; while the arguments in favour of it are the close resemblance between the products of thermal springs and metalliferous lodes, and the common occurrence of oblique runs of metal in a lode.

(d.) *Infiltration from the Sides*.—First proposed by Gerhard in his "Mineral Reichs," 1781. The arguments against this theory are, that veins rarely occur singly but in defined districts, and that the bed-rock is generally dry until the lode is cut. The arguments in its favour are, that new crops of ore have been found in old veins; that a change in the bed-rock often affects the nature or quantity of the ore; that veins are seldom found in hard crystalline rocks except where decomposed or much fractured; and that it accounts for flat veins,

pipe veins, and gash veins. This theory supposes that the strata received their metals from the ocean at the period of their deposition, and that subsequent changes have brought them together into veins.

On the whole, it appears most probable that veins have been filled by infiltration from their sides during the progress of metamorphism.

The mode of deposition or precipitation of the metals in veins is a chemical question, and does not belong to geology.

Age of Metals.—Most of the ordinary metals appear to be of all ages. Gold is found in the Palæozoic rocks of Australia, in veins which are cut off by Mesozoic rocks. It occurs in Jurassic rocks in California, and associated with pyrites in the Mesozoic rocks of Australia and Chili. It is found associated with silver in Cainozoic rocks in Hungary and New Zealand; while Werner mentions gold as having been found in lignite or “semi-bituminised wood” at Zalathna in Transylvania,* and it has also been found in the same position associated with pyrites in Australia.

Copper is found in Cainozoic rocks in Italy and Algeria; and zinc, lead, and arsenic in Hungary and Italy.

* *New Theory of the Formation of Veins*, 1791. Translated by C. Anderson, 1809. P. 143.

CHAPTER XIX.

THE ART OF MINING.

THE different methods of mining may for the sake of convenience be arranged under three heads: (1) *Vein Mining*, or the extracting of minerals from veins which have a more or less perpendicular direction; (2) *Bed Mining*, or the extracting of minerals or rocks from rock-beds which have a more or less horizontal direction; and (3) *Alluvial Mining*, or the extracting of minerals from alluvial deposits.

Vein Mining. *Commencement of Works.*—Nearly all veins are worked by means of shafts, which are either

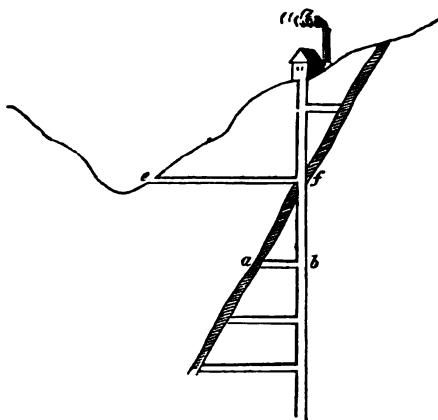


Fig. 25.

inclined with the dip of the vein, or more commonly perpendicular, and put down in such a position as to

come upon the vein at a depth of from ten to thirty fathoms, the superficial parts of all but auriferous veins

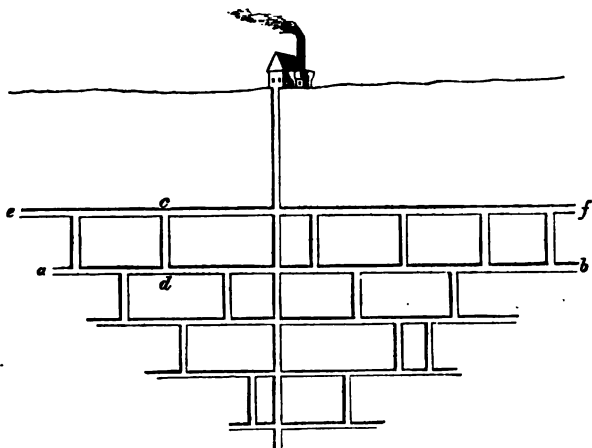


Fig. 26.

being usually unproductive. On cutting the vein, horizontal galleries, called *levels* (Fig. 26, *a b*), are driven along it in opposite directions. The shaft may then be continued vertically or obliquely. The first is the more expensive, but it is ultimately the most advantageous, as an inclined shaft is not well adapted for the application of pumps and raising machinery, an evil that increases much with the depth of the mine.

If the shaft is continued in a perpendicular direction, transverse levels (Fig. 25, *a b*), called *cross-cuts*, are driven from it into the vein, and from this other levels are driven along the vein, the distance between levels being usually ten fathoms. From each level small inclined shafts, called *winzes* (Fig. 26, *c d*), are sunk to the level below,

thus dividing the vein into rectangular masses, which can be examined all round, and only worked at the productive parts. They also allow the air to circulate through the mine. Where the ore is tolerably continuous, winzes should be sunk every twenty or thirty fathoms, their position being regulated, if possible, so as to prove the richest parts of the vein. The winzes of the second level should be situated midway between those above them, as this gives some indication of the richness of the middle of the blocks above and below them.

Extension of the Works.—When the levels become considerably extended, ventilation becomes defective owing to the number of men employed, more candles being used, and more blasting going on. The expense also of transporting the ore and rubbish is much increased, and one or more new shafts must be sunk. In order to avoid the expense and delay of cross-cuts, the new shafts should be placed so as to intersect the vein much deeper than the old one.

Extracting the Ore.—The blocks of ore are worked out upwards from the bottom, and the excavations are so arranged that the ore may readily fall down to the level below, from whence it is carried in tram-waggons to the shaft. The faces being worked are called *stopes*. When a vein is not hard the ore may be broken out with a pick, but blasting has generally to be resorted to.

In working a mine it is desirable to keep the quantity of ore raised as nearly as possible uniform; a portion, therefore, of the ore laid bare should always be kept as a reserve. In making drives, there is sometimes great danger from water breaking into the mine, especially in "rise-workings." When this is expected, bore-holes should be carried ten or twelve feet in advance of the

drive, and wooden plugs and mallets must be kept on hand for filling up the bore if water should be struck.

Timbering.—Both shafts and levels are usually timbered. Shafts should always be close timbered, on account of the water running down their sides, and the constant friction in extraction of the ore. In levels the closeness of the timbering depends upon the nature of the roof and walls. The frames for timbering levels consist of two uprights, slightly inclined to one another, called *standards*, and a cross piece, called a *cap*, resting upon them. If the roof is very bad, planks are placed longitudinally above the caps from one cap to another.

When a stope approaches a level from below, the frames of the level are secured by placing a lower cross piece to keep the bottom of the standards open, and a strut is often added to support the side that bears the greatest pressure.

Drainage.—In most mines pumps are soon required for raising the water that flows into the shaft and drives; but occasionally the water can be drained off to a certain depth by means of a level communicating with the surface. This is called the *adit level* (Figs. 25 and 26, *ef*).

Bed Mining.—A coal mine may be taken as the type of bed mining, but salt and some iron ores are worked in the same way. When possible a point is selected in a valley where the bed is exposed to view, and a drive, called a *day level*, is commenced either along the strike of the bed itself, or, if this is impracticable, as a cross-cut from below into it. When the seam is reached, a level, called in this case a *bord*, is driven along the strike, and *headings* are driven at right angles to it at about every eight or nine yards on the rise of the bed. When part of the bed is inaccessible by day levels re-

course must be had to winzes, and when these have proceeded for a considerable distance a shaft will be required. If a coal seam dips pretty rapidly, it is often worked by an inclined shaft from the outcrop.

All coal has a minute structure, analogous to cleavage, by which it splits more easily in one direction than in any other, except the plane of bedding. This is called the *face* or *cleft* of the coal, and its direction generally remains constant over large areas. In laying out the works attention has to be paid to the direction of the face, as it is much easier to drive along the face than across it.

Coal mines are worked on two systems.

Post-and-Stall or Bord-and-Pillar System.—Large rectangular pillars are at first left between the bords and headings, and when all the galleries are finished the pillars are gradually removed. The roof is at first supported by timber, but as this is taken away it falls in. In order to avoid as much as possible the danger arising from the accumulation of fire-damp in old workings, the mine is divided into districts or *panels*, separated from each other by walls of coal forty or fifty yards thick, and each panel is worked out in succession. In this system the working drifts have to be driven at right angles to the face.

Long-wall or Long-work System.—The whole breadth of coal is removed in a long continuous line, the roof being supported by two or more rows of timber props, which are gradually removed inward as the coal is excavated, allowing the roof to fall down a few feet behind the workmen. There are two methods of working on this system. Either bords may be driven to the boundary of the mine and the coal worked out backwards, or the coal may be worked outwards from the shaft, leaving

what are called *gob-roads* through the fallen roof, or *goaf*, for taking the coal to the shaft. In all cases a large mass of coal must be left round the shaft as a shaft pillar, having only the bords cut through it.

In this system the working faces are generally along the face of the coal.

Ventilation of Mines.—In coal mines, besides the ordinary impurities, the air is often contaminated by the escape of gases from the coal. These are chiefly *choke-damp*, or carbonic acid gas, and *fire-damp*, or light carburetted hydrogen.

Choke-damp is heavier than air, and collects at the bottom of mines, while fire-damp is lighter than air, and when mixed with it forms an explosive compound.

When fire-damp is present in the proportion of one-twentieth of the volume of air, the flame of the safety-lamp elongates; if the proportion is one-twelfth, a blue light is seen to surround the flame; if the proportion increases to one-fifth, the lamp is filled with a brilliant light, in which the lamp flame is not seen; while when the proportion gets to be one-third the lamp goes out. Where a safety-lamp continues to burn, the air may be breathed without danger; but when the lamp gets filled with flame the wire gauze gets hot, a slight breath of wind makes the flame pass through, and an explosion follows.

With choke-damp a candle ceases to burn brightly long before the air is sufficiently bad to destroy life, so that it is impossible to work a mine in this state.

The minimum quantity of fresh air required to support life is fifteen to eighteen cubic feet per minute for each man, consequently a good system of ventilation is of the first importance in a mine.

Natural Ventilation.—The simplest mode of ventilation is to have two shafts opening at different levels, and connected at the bottom. Then when the temperature of the mine is greater than that at the surface, the pressure at the bottom of the shaft that has the lower opening will be greater than that at the bottom of the longer shaft, and a current of air will descend through the shorter shaft, or *downcast*, and ascend through the longer shaft, or *upcast*. If the temperature at the surface is greater than that of the mine the reverse will take place, and the longer shaft will become the downcast. On level ground this difference in level between the openings of the two shafts can be obtained by erecting a chimney over one of them. This is called natural ventilation, and works best in winter, for at that time there is a greater difference between the temperature in the mine and that on the surface.

Artificial Ventilation.—When a larger current of air is required, some means of artificial ventilation is resorted to. Air is driven down a shaft by means of a fan or falling water, or it is drawn up by pumps or screws, or it is driven up one shaft by means of a fire lighted at the bottom of it.

The currents of air are directed and regulated in the mine by means of doors.

Alluvial Mining is the art of obtaining metals from the débris resulting from the denudation of rocks. Fragments of rock and vein-stones containing metals are brought down by rivers, and the constant attrition they undergo during their journey down to the sea separates the metals from the vein-stones, and then, being of different specific gravities, the heavier metals collect together in the beds of the rivers, while the lighter

vein-stones pass onwards and form layers above the metals.

Alluvial mining may be conveniently divided under four heads.

Surfacing, which is washing the earth near auriferous reefs to obtain the gold, often united with the vein-stone, washed down by the rain.

Beach Mining.—Obtaining gold from sea-beaches, where it has been washed up and sorted by the action of the waves.

Shallow Workings.—Sinking pits, &c., in valleys to obtain off the surface of the underlying rocks the gold that has been brought down by the river. Sometimes these mines are worked on the hydraulic system, the whole of the alluvial deposits being washed away by streams of water directed against them.

Deep Workings.—Obtaining auriferous earth or *wash-dirt* from the bottoms of old water-courses in localities where the river no longer runs. These old bottoms are called *deep leads* or *gutters*, and are sometimes worked like a flat vein in vein mining.

Describing Mines.—The description of a mining district ought to contain an account of its external surface, its situation and limits, of the rocks that it contains, and the relations that they bear to each other; also a general account of the mines, as well as a particular account of each, embracing the following heads:—

- (a.) Locality and extent of the property.
- (b.) The bed-rock, its nature, structure, and condition near the veins.
- (c.) The position and size of the veins or beds.
- (d.) The predominating ores and vein-stones, mode of filling, &c.

- (e.) The rarer ores and vein-stones.
- (f.) Intersection of veins, leaders, stringers, &c.
- (g.) Description of the workings.
- (h.) Extent worked out and yield.

In describing a mine four plans are wanted—

- (1) Ground-plan ; (2) longitudinal section (Fig. 26);
- (3) transverse section (Fig. 25) ; and (4) horizontal plan of workings.

CHAPTER XX.

GEOLOGICAL SURVEYING.

THE object of the geological survey of a country is to make out the structure of the surface of the earth in that district ; that is, to ascertain the extent, thickness, position, and relative age of each formation found in the district, and it is from the facts thus ascertained that the geological history of that portion of the earth is deduced.

Procedure in the Field.—In order to commence work the field geologist requires a *clinometer*, which is a compass to which is attached some apparatus for measuring the dip,* a hammer to make fresh fractures of the rocks to be examined, a notebook, and the best topographical map he can procure. The amount of detail with which the geology of a district can be worked out depends entirely upon the accuracy and scale of the topographical map. For the sake of convenience in handling, the map should be cut up into portions, which, when once folded, will go into the notebook.

* The most convenient is Ramsay's clinometer, made by Messrs Troughton & Simms, London, which is about the size and shape of a watch.

Thus equipped, the geologist must then examine the best exposure of the rocks that he can find, and enter in his notebook the composition, thickness, and dip of the beds, whether they contain fossils, &c., and mark upon his map the position of the outcrop. This he does at all the exposures he can find, trying to correlate the different beds, and filling in as he goes the supposed boundary between each rock or formation between the observed points of outcrop; and so, by travelling all over the country, he gradually fills up his map. In doing this there are several important points to be attended to. In the first place, he must remember that all rocks crumble away, and that the *débris* descends to a lower level, and consequently the line of outcrop lies above the *débris*. He must also remember that the line of outcrop depends upon the dip of the beds and the inclination of the slopes of the hills.* For instance, when a horizontal bed is cut through by a valley, the line of outcrop forms a loop up the valley following the contour line of the hills. If the bed dips up the valley, the loop will be shortened in proportion to the amount of dip, while when the bed is vertical it will crop out straight across the valley, along the line of strike. If the bed dips down the valley at a less angle than the slope of the valley itself, the loop up the valley will be elongated; but if the dip is greater than the slope of the valley, the loop will point down the valley, the greater the dip the shorter being the loop, until when the bed becomes vertical it will crop out straight across the valley, as in the last case.

Faults also affect the line of outcrop very much. Faults that traverse the rocks at right angles to the strike throw the outcrop of each bed back on the down-throw

* This is best taught by means of Sopwith's geological models.

side, the amount of surface displacement depending upon the throw of the fault and the dip of the beds. At the same time there is also a lateral displacement or opening between the two ends of the outcrops depending upon the inclination of the fault to the horizon. When the fault is parallel to the strike, the same bed is made to reappear again at the surface, as if that part on the down-throw side was an older bed than that on the up-throw side. Of course all kinds of intermediate inclinations of the fault with the strike of the beds occur. The student, however, must be cautioned not to put down to faults and dislocations all the difficulties he may encounter in his survey, but try to work out patiently the true relations of the beds.

Another difficulty will be found in the different appearance of the same rock in different states of decomposition; and the student should always carefully observe the way in which each bed weathers, or he will be liable to fall into very great errors. The geologist should also make sketches of any exposure of rocks that he thinks of particular interest, and outline drawings of the surface of those districts through which he proposes to make sections. In the evening, when the day's work is over, he should tint his map with different colours for the different formations, and from his map and notebook prepare his sections.

Construction of Sections.—*Diagrammatic sections* for helping to convey an idea of the general structure of the country are made by sketching an outline of the surface crossed by the section, then measuring from the geological map the position of the outcrops of the formations, and then sketching in the dips approximately from the notebook.

True sections, whether on a natural scale—that is, when the horizontal and vertical scales are the same—or when the vertical scale is larger than the horizontal one, can only be made when the district has been well surveyed topographically and levelled; and even then the geologist has to run his own line of levels along the section he is making. If, however, the heights of the principal points have been correctly ascertained, a good aneroid is quite sufficient for filling in the intermediate places.

When the dip is in the same direction as the section, it can be laid down at once; but if, as often happens, it is more or less oblique to the line of section, a correction will have to be applied to reduce it to the apparent dip on the line of section (see Appendix, Proposition IV.) If the two scales differ, the dip must be first drawn with the necessary exaggeration, and then corrected for obliquity.

These sections are usually called *horizontal sections*, but the name is very incorrect; and *transverse sections* would be far preferable, as they are generally taken transverse to the strike of the rocks.

Another kind of section, called a *vertical section*, is often employed to show to the eye the relative thickness of beds or formations. It consists of drawing to scale the relative thicknesses of the different rocks placed under one another, as if passed through in a vertical boring. This kind of section is very useful in bringing before the eye the horizontal thinning out of beds, by comparing together vertical sections taken at different places.

Method of Examining a New Country.—The first thing to be done is to make an inspection of the whole country, in order to ascertain its general geo-

logical structure and the chronological arrangement of the rocks. This preliminary or *reconnaissance survey* should all be done by the same person. He passes rapidly over the country, neglecting minor details, but roughly filling in on his map the outlines of the larger formations. He examines all the localities that he can hear of for fossils, and selects the best districts for working out the formations in detail. For this purpose a map of ten or twelve miles to the inch is sufficiently large. Until this reconnaissance survey is completed no conclusions can be drawn as to the extent or position of mineral-bearing beds.

Then follows the *detailed survey*. Fossil collectors are sent to the different localities for fossils, and any number of assistants can be employed in different districts; but the accuracy and amount of detail of any geological survey must always depend upon the topographical map supplied to the geologist. No detailed survey can be made on a scale less than one inch to the mile, while for important coal-bearing districts six inches to the mile is small enough.

APPENDIX.

A.

PROBLEMS IN GEOLOGICAL SURVEYING.

PROPOSITION I.

To find the thickness of an inclined bed whose dip is known, from a horizontal measurement on the surface.

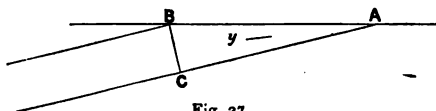


Fig. 27.

Let AB be the outcrop of the bed, and BAC the angle of dip ($= y$). Draw BG at right angles to AC. Then BC will be the thickness of the bed.

$$\text{Then } \sin y = \frac{BC}{AB}$$

$$BC = AB \sin y.$$

PROPOSITION II.

To find the depth below the surface of a bed whose dip is known, at a given horizontal distance from the outcrop.

Let AC represent the bed, and B the point at a known horizontal distance (AB) from the outcrop (A), at which the

depth of the bed is required. Draw BC at right angles to AB, and let the angle of dip (BAC) = y .

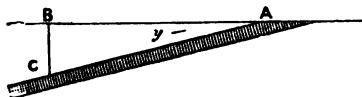


Fig. 28.

$$\text{Then } \tan. y = \frac{BC}{AB}$$

$$BC = AB \tan. y.$$

If the surface is not horizontal, the difference in level between the two stations must be found, and must be added to or subtracted from BC, according as the surface at B is higher or lower than A.

N.B.—The throw of faults can be found by means of this proposition, the distance AB representing the distance between the two outcrops of the same bed.

PROPOSITION III.*

Given the apparent dip at a given angle with the true dip, to find the true dip.

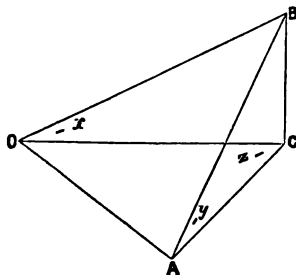


Fig. 29.

Let OA be the direction of the strike, and OC the direction of the section on which the apparent dip is measured. Draw AC at right angles to OA. Then AC is the direction of the true dip. Draw BC vertical, and make the angle COB equal to the observed apparent dip. Join AB. Then the angle CAB is the true dip.

* Given by Mr W. Hopkins to Professor J. Beete Jukes, and printed by him in his Report on the Geological Survey of the South Staffordshire Coal-field, in the Memoirs of the Geological Survey of Great Britain.

Let the angle $OCA = s$, $CAB = y$, and $COB = x$.

$$\text{Then } \tan. y = \frac{BC}{AC}$$

$$\text{but } BC = OB \sin x$$

$$\text{and } AC = OC \cos. s \\ = OB \cos. x \cos. s$$

$$\therefore \tan. y = \frac{\sin x}{\cos. x \cos. s}, \\ = \frac{\tan. x}{\cos. s} \\ = \tan. x \sec. s,$$

which gives the true dip.

From this we also see that

$$\tan x = \frac{\tan. y}{\sec. s} \\ = \tan. y \cos. s,$$

which gives the apparent dip when the true dip and angle of obliquity are known.

N.B.—This is used when constructing oblique sections.

PROPOSITION IV.

Given the apparent dip in any two known directions, to find the true dip.

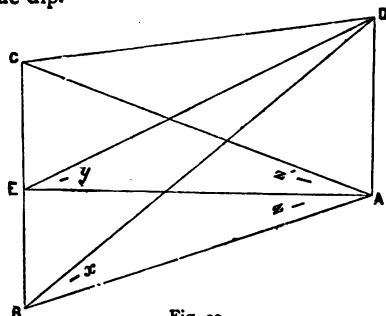


Fig. 30.

Let AB and AC represent the directions of the two apparent dips. Draw AD vertical, and make the angles ABD

and ACD equal respectively to the two apparent dips. Join CB. Then CB represents the strike.

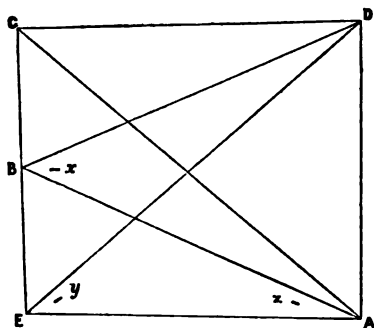


Fig. 31.

From A draw AE at right angles to CB (fig. 30), or CB produced (fig. 31), and join ED. Then EA represents the direction, and AED the inclination of the true dip.

Let the angles $ABD = x$, $ACD = x'$, $AED = y$, $BAE = z$, $EAC = z'$, $ACB = a$, and $ABC = b$.

Then $a + b = 180^\circ - (z + z')$ in fig. 30; or
 $= 180^\circ - (z - z')$ in fig. 31.

$CA = AD \cot. x'$, and $BA = AD \cot. x$,

$$\text{and } \tan. \frac{1}{2}(a - b) = \frac{(CA - BA) \tan. \frac{1}{2}(a + b)}{CA + BA}$$

$$b = \frac{1}{2}(a + b) - \frac{1}{2}(a - b)$$

and $z = \frac{1}{2}b \mp 90^\circ$, according as b is greater

or less than a right angle, which gives the bearing of the true dip, and by the last proposition

$$\tan. y = \tan. x \sec. z,$$

which gives the inclination.

PROPOSITION V.

Given the dip on each side of an anticlinal or synclinal curve, to find the direction of the axis.

Let OC and OB represent the bearings of the two dips. Draw OD vertical, and make the angles OCD and OBD equal to the dip on either side of the curve. Draw BA horizontally at right angles to OB , and CA horizontally at right angles to OC . Join AO , AD , and BC .

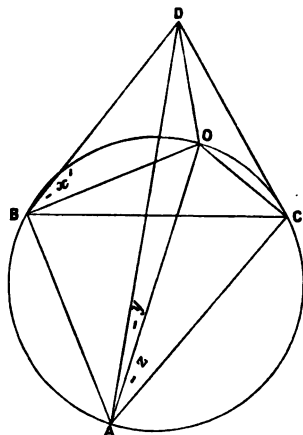


Fig. 32.

Then CA and BA represent the strike on either side of the curve; AO represents the bearing of the axis, and the angle DAO its inclination.

Let the angles $OCD = x$, $OBD = x'$, $OAC = z$, $OAB = z'$, and $DOA = y$.

Then since the angles ABO and ACO are both right angles, B and C lie on the circumference of the circle of which AO is a diameter.

Hence the angle OBC equals the angle OAC , being in the same segment; and for the same reason the angle OCB equals the angle OAB .

$$\therefore \angle OCB = s', \text{ and } \angle OBC = s$$

$$\text{also } CO = OD \cot. x, \text{ and } BO = OD \cot. x'$$

$$\therefore \tan. \frac{1}{2} (s' - s) = \frac{(\cot. x - \cot. x') \tan. \frac{1}{2} (s' + s)}{\cot. x + \cot. x'}$$

$$s = \frac{1}{2} (s' + s) - \frac{1}{2} (s' - s),$$

which gives the bearing of the axis.

$$\text{Also } \tan. y = \frac{DO}{AO}$$

$$DO = OC \tan. x$$

$$AO = OC \operatorname{cosec}. s$$

$$\therefore \tan. y = \frac{\tan. x}{\operatorname{cosec}. s}$$

$$= \tan. x \sin. s,$$

which gives the inclination of the axis.

N.B.—The axis of an anticlinal curve will incline downward towards the angle formed by the two lines of strike, while the axis of a synclinal curve will incline upwards towards that angle.

B.

TABLE OF SIGNS AND COLOURS USED BY
THE GEOLOGICAL SURVEY OF GREAT
BRITAIN AND IRELAND.

- Roches moutonnées, not striated.
- ⊖ Roches moutonnées, striated, but direction of ice-flow not apparent.
- ⊖→ Roches moutonnées, showing direction of ice-flow.
- Plane or flat surface, striated.
- ⊖→ Plane or flat surface, showing direction of ice-flow.
- + Horizontal beds.
- ⊥ Vertical beds, longest line the direction of strike.
- ∞ Contorted beds.
- × Undulating beds.
- ↓ Dip from observation.
- ↙ Dip in underground workings.
- ‡ Dip from information.
- ↙ or × Undulating beds, with general dip in direction of arrow.
- ↗ Contorted beds, with general dip in direction of arrow.
- ∧ Cleavage, longest line the strike, shortest the dip.
- ‡ Anticlinal axis.
- * Synclinal axis.
- B.H. Bore hole.
- ↑ D.H. Day level.
- ⊖ Mine shaft.
- == Colliery levels.

	Limestone quarries and limekilns.
S. Q.	Slate quarries.
	Quarries and brickyards.
	Gold.
	Silver.
	Tin.
	Lead.
	Zinc.
	Copper.
	Iron.
	Manganese.

Gold lines show mineral veins.

Gold rings show pipe veins.

Gold dots show alluvial metals.

Thick black lines show coal crops.

Interrupted black lines show coal crops where doubtful.

Interrupted lines show a doubtful boundary.

White lines show faults on the surface.

Yellow lines show faults underground.

INDEX.

- ACCESSORY** minerals, 18.
 Albite, composition of, 19.
 Alteration, operation of, 35.
 Andesite, composition of, 55 ;
 the name introduced by Leopold von Buch, *ib.*
 Angite, description of, 20.
 Antonio Moro, early contribution by, to the science of geology, 10.
 Aphanite, composition of, 56.
 Apsides, revolution of the, 14.
 Arenaceous rocks, description of, 37.
 Argillaceous rocks, description of, 38.
 Axes, anticlinal and synclinal, 43.

BASALT, composition of, 57.
 Beds, intercalation of, 28; change in the lithological character of, *ib.*
 Biotite or magnesian mica, composition of, 20.
 Blind-coal, origin of, 35.
 Breccia, origin of, 37.
 Buckland, Dr, contributions to the science of geology by, 11.

CALCAREOUS rocks, description of, 40.
 Calcite, composition of, 21.
 Carbonaceous rocks, description of, 41.
 Chalk, a variety of limestone, 40.
 Chlorite, composition of, 20.
 Chlorite-schist, composition of, 39.
 Clay, conversion of, into porcelanite, 35 ; composition of, 38.
 Cleavage, planes of, 17, 66.
 Coal, formation of, 31 ; composition of, 41.
 Coal-mines, worked on two systems, 108.
 Concretions, description of, 97 ; kinds of, 98.
 Conglomerates, composition of, 37.
 Consolidation, description of, 34.
 Contortions, origin of, 44.
 Coral islands, origin of, 68.
 Coral reefs, composition of, 30 ; rate of growth, 31.
 Cosmical relations of the earth, 13.
 Crystalline schists, the age of, twofold, 90.
 Crystals, what they are, 17.
 Curves, anticlinal and synclinal, origin of, 44.

DECOMPOSITION, operation of, 36.
 Denudation, operation and effects of, 22 ; sub-aerial, *ib.* ; marine, 23 ; underground, 24 ; proofs of former, 74.
 Deposition, action of, 25 ; rates of, 26.
 Deposits, the action of rivers in forming, 96.

- Dip, the, 42.
 Dolerite, composition of, 56.
 Dolomite, composition of, 21, 40.
 Dykes, description of, 62.
- EARTH, composition of the, 15 ;
 mutation of the, *ib.* ; internal
 temperature of the, 16 ; move-
 ments of the surface of, 67 ;
 moves while the sea remains
 stationary, 70 ; causes, *ib.*
- Earthquakes, cause of, 73 ; their
 action, *ib.* ; the centre of im-
 pulse, *ib.* ; the seismic vertical,
ib. ; the angle of emergence,
 74 ; coseimal lines, *ib.* ; the
 velocity of transit, *ib.* ; the ve-
 locity of shock, *ib.* ; amplitude
 of the earth wave, 75 ; the seis-
 mometer, *ib.* ; waves of sound,
 78 ; ocean waves caused by,
ib. ; secondary effects of, 79 ;
 distribution of, *ib.*
- Ecliptic, change of obliquity of
 the, 15.
- Equinoxes, precession of the,
 14.
- Erosion, contemporaneous, 27.
- Eruptive rocks, description of,
 50 ; owe their origin to fusion,
ib. ; are divided into different
 orders and groups, 51 ; older
 and newer, 57 ; determination
 of, 58 ; list of, 59 ; mode of oc-
 currence of the older, 60 ; con-
 temporaneous eruptive rocks,
ib. ; intrusive eruptive rocks,
 61 ; evidence of age, 90.
- FAULTS, description of, 65.
 Felspar, description of, 18.
- Felspathic rocks, description of,
 53.
- Felstone, composition of, 52.
- Florida reef, opinions as to com-
 position of, 30.
- Foliation, origin of, 34.
- Fossils, description of, 80 ; chiefly
 of marine origin, 81 ; petrified
 fossils, 82 ; rare in sandstone,
 and more common in lime-
 stone and clay, *ib.* ; use in de-
 termining the ages of rocks, 86.
 Fossil shells, earliest notice of, 9.
- GARNET rocks, description of, 21.
 Geological record, imperfection
 of the, 83 ; terms, explanation
 of, 88.
- Geology, the science of, what it
 is, 9 ; early discoveries in, 10.
- Gneiss, composition of, 39.
- Granite, composition of, 51 ; first
 scientifically defined by Wer-
 ner, 52.
- Granitoid-gneiss, composition of,
 39.
- Greenstone, composition of, 56.
- Gypsum, composition of, 21.
- HORNBLLENDE, description of, 20.
 Hornblende-schist, composition
 of, 39.
- Hutton, Dr James, early teach-
 ings of scientific geology by, 10.
- INVERSION, what it is, 44.
- Itacolumite, composition of, 38.
- JOINTS, description of, 63.
- LABRADORITE, composition of,
 19.
- Lakes, their origin, 94.
- Lamination, process of, 25 ; false
 bedding or oblique, 27.
- Leibnitz, suggestion of, as to the
 earth's incandescence, 10.
- Leonardo da Vinci, early contri-
 bution by, to the science of
 geology, 9.
- Limestone, formation of, 29 ;
 composition of, 40 ; magnesian,
ib. ; compact, *ib.* ; granular, *ib.*

- Lignite, composition of, 41.
 Liparite, composition of, 52.
 Lyell, Sir C., contributions to the science of geology by, 11.
- MARL, composition of, 38.
 Melaphyre, description of, 55.
 Metals, the age of, 103.
 Metamorphism, meaning of the term, 33; operations of, 34, 35.
 Micaceous rocks, description of, 19.
 Mica-schist, composition of, 39.
 Mineral, a, what it is, 17.
 Mining districts of two kinds, 99.
 Mining, the art of, 104; different methods, *ib.*; vein-mining, *ib.*; bed-mining, 107; ventilation, 109; alluvial mining, 110; mode of describing a mining district, 111.
 Mountains, the character of, is twofold, 91; their external character very little influenced by their internal structure, *ib.*
 Muscovite or potash mica, composition of, 20.
- NECKS, description of, 62.
- OLIGOCLASE, composition of, 19.
 Olivine, composition of, 21.
 Orthoclase or potash felspar, composition of, 19.
 Outcrop, the line of, 43.
 Outliers proofs of denudation, 72.
 Overlap, how formed, 46.
- PALÆONTOLOGY, its relation to geology, 80.
 Peat, where found, 32; rate of growth, *ib.*; composition, 41.
 Phonolite, description of, 55.
 Phyllite, composition of, 39.
 Physiography, the study of the minor features of the earth's surface, 91.
- Plains of deposition, 95; of denudation, *ib.*
 Plumbago, description of, 41.
 Porphyrite, composition of, 54.
 Problems in geological science, 117.
 Propylite, composition of, 54; the name introduced by Baron Richthofen, *ib.*
 Pseudomorphism, description of, 33.
 Pyroxenic rocks, description of, 20, 56.
- QUARTZITE, composition of, 37.
 Quartz or silica, description of, 18.
 Quartz - porphyry, composition of, 52.
 Quartz-schist, composition of, 37.
- REPLACEMENT, effects of, 33.
 Rhyolite, composition of, 53.
 Ripple-marks, formation of, 27.
 River deposits, the action of rivers in forming, 96.
 Rock-forming minerals, list of, 18.
 Rock-salt, composition of, 21.
 Rocks, chronological classification of, 84; evidence of their relative ages, 85; classification by organic remains, 87; standard of the European, 88.
 Rocks, classification of, 17.
 Rocks, structure of, 63.
 Rocks, weathering of, 22; inorganically derived sedimentary, 23; organically derived sedimentary, 24; the geological meaning of the term, *ib.*
- SANDSTONE and slate, formation of, 25.
 Sandstone, composition of, 37.
 Sea, the, remains stationary, while the land rises and falls, 70.

- Sections, geological, mode of distinguishing various strata in, 26.
- Sedimentary rocks, formation of, 25; originally horizontal, 29; description of, 36; list of, 42; test of their age, 85.
- Serpentine, composition of, 20; description of, 57.
- Silicious rocks, description of, 51.
- Slate, composition of, 38.
- Slickensides, description of, 66.
- Smith, William, constructs the first geological map of England, 10; value of his labours, *ib.*
- Stalactites, formation of, 25.
- Stalagmites, formation of, 25.
- Strata, position of, 42.
- Stratification, planes of, 25.
- Strike, the, 43.
- Surveying, geological, the object of, 112; procedure in the field, *ib.*; the clinometer, *ib.*; construction of sections, 114; diagrammatic, true, horizontal, transverse, and vertical sections, 115; method of examining a new country, *ib.*; the detailed survey, 116.
- Swallow-holes, formation of, 24.
- Swells or rolls, origin of, 27.
- Syenite, composition of, 53.
- Syenitic-granite, composition of, 52.
- TABLE of signs and colours used by the Geological Survey of Great Britain and Ireland, 123.
- Table showing the relative thickness, the changes of fauna, and the proportional rate of change of each of the three larger eras, 89.
- Talc rocks, description of, 20, 21.
- Talc-schist, composition of, 39.
- Temperature, stratum of invariable, 17.
- Thomson, Sir W., contributions to the theory of geological evolutions by, 12.
- Trachylite, composition of, 57.
- Trachyte, composition of, 54.
- Trachyte tuff, description of, 55.
- Tuff, composition of, 53.
- UNCONFORMITY, what is meant by, 45.
- VALLEYS, their formation, 91; not owing to one unvarying cause, 93.
- Veins, mineral, the character of, 97; non-metalliferous, 98; metalliferous, 99; kinds of, *ib.*; contents, 100; direction of, *ib.*; origin, 101; filling of, *ib.*
- Verde-antique, a compound of limestone and serpentine, 40.
- Volcanoes, action of, 46; paroxysmal eruptions, *ib.*; lava, 48; massive eruptions, 49; differences between paroxysmal and massive eruptions, *ib.*
- WHETSTONE, a variety of slate, 38.

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